Chapter 22. Africa

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Executive Summary

Evidence of warming over land regions across Africa, consistent with anthropogenic climate change, has increased (*high confidence*). Decadal analyses of temperatures strongly point to an increased warming trend across the continent over the last 50-100 years. [22.2.1.1]

Mean annual temperature rise over Africa, relative to the late 20th Century mean annual temperature, is *likely* to exceed 2° C in the A1B and A2 scenarios by the end of this century (*medium confidence*). Warming projections under medium scenarios indicate that extensive areas of Africa will exceed 2° C by the last two decades of this century relative to the late 20th Century mean annual temperature and all of Africa under high emission scenarios. Under a high RCP, that exceedence could occur by mid-century across much of Africa and reach between 3 and 6° C by the end of the century. It is *likely* that land temperatures over Africa will rise faster than the global land average, particularly in the more arid regions, and that the rate of increase in minimum temperatures will exceed that of maximum temperatures. [22.2.1.2]

A reduction in precipitation is *likely* over Northern Africa and the south-western parts of South Africa by the end of the 21st Century under the A1B and A2 scenarios (*medium to high confidence*). Projected rainfall change over sub-Sarahan Africa in the mid- and late 21st Century is uncertain. In regions of high or complex topography such as the Ethopian Highlands, downscaled projections indicate *likely* increases in rainfall and extreme rainfall by the end of the 21st Century. [22.2.2.2, 22.2.3]

African ecosystems are already being affected by climate change, and futre impacts are expected to be substantial (*high confidence*). There is emerging evidence on shifting ranges of some species and ecosystems due to elevated CO_2 and climate change, beyond the effects of land-use change and other non-climate stressors (*high confidence*). Ocean ecosystems, in particular coral reefs, will be affected by ocean acidification and warming as well as changes in ocean upwellings, thus negatively affecting economic sectors such as fisheries (*medium confidence*). [22.3.2, Table 22-3]

Climate change will amplify existing stress on water availability in Africa (*high confidence*). Water resources are subjected to high hydro-climatic variability over space and time, and are a key constraint on the continent's continued economic development. The impacts of climate change will be superimposed onto already water-stressed catchments with complex land uses, engineered water systems, and a strong historical socio-political and economic footprint. Strategies that integrate land and water management, and disaster risk reduction, within a framework of emerging climate change risks would bolster resilient development in the face of projected impacts of climate change. [22.3.2.2, 22.3.3]

Climate change will interact with non-climate drivers and stressors to exacerbate vulnerability of agricultural systems, particularly in semi-arid areas (*high confidence*). Increasing temperatures and changes in precipitation are *very likely* to reduce cereal crop productivity. This will have strong adverse effects on food security. New evidence is also emerging that high-value perennial crops could also be adversely affected by temperature rise (*medium confidence*). Pest, weed and disease pressure on crops and livestock is expected to increase as a result of climate change combined with other factors (*low confidence*). Moreover, new challenges to food security are emerging as a result of strong urbanization trends on the continent and increasingly globalized food chains, which require better understanding of the multi-stressor context of food and livelihood security in both urban and rural contexts in Africa. [22.3.4, 22.3.4.3, 22.3.4.5]

Progress has been achieved on managing risks to food production from current climate variability and near-term climate change but these will not be sufficient to address long-term impacts of climate change (*high confidence*). Livelihood-based approaches for managing risks to food production from multiple stressors, including rainfall variability, have increased substantially in Africa since the IPCC's Fourth Assessment Report (AR4). While these efforts can improve the resiliency of agricultural systems in Africa over the near term, current adaptations will be insufficient for managing risks from long-term climate change, which will be variable across regions and farming system types. Nonetheless, processes such as collaborative, participatory research that includes scientists and farmers, strengthening of communication systems for anticipating and responding to climate risks, and increased flexibility in livelihood options, which serve to strengthen coping strategies in agriculture for near-term risks from climate variability, provide potential pathways for strengthening adaptive capacities for climate change. [22.4.5.4, 22.4.5.7, 22.4.6, 22.6.2]

Climate change may increase the burden of a range of climate-relevant health outcomes (*medium confidence*). Climate change is a multiplier of existing health vulnerabilities (*high confidence*) including insufficient access to safe water and improved sanitation, food insecurity, and limited access to health care and education. [22.3.5.1] Detection and attribution of trends is difficult because of the complexity of disease transmission, with many drivers other than weather and climate, and short and often incomplete datasets. Evidence is growing that highland areas, especially in East Africa, could experience increased malaria epidemics due to climate change (medium evidence, very high agreement). The strong seasonality of meningococcal meningitis and associations with weather and climate variability suggest the disease burden could be negatively affected by climate change (*medium evidence* and *high agreement*). The frequency of leishmaniasis epidemics in sub-Saharan Africa is changing, with spatial spread to peri-urban areas and to adjacent geographic regions, with possible contributions from changing rainfall patterns (*low confidence*). Climate change is projected to increase the burden of malnutrition *(medium confidence*), with the highest toll expected in children. [22.3.5.3]

In all regions of the continent, national governments are initiating governance systems for adaptation and responding to climate change, but evolving institutional frameworks cannot yet effectively co-ordinate the range of adaptation initiatives being implemented (*high confidence)*. Progress on national and sub-national policies and strategies has initiated the mainstreaming of adaptation into sectoral planning. [22.4.4] However, incomplete, under-resourced and fragmented institutional frameworks and overall low levels of adaptive capacity, especially competency at local government level, to manage complex socio-ecological change translate into a largely *ad hoc* and project-level approach, which is often donor-driven. [22.4.2, 22.4.4.3, 22.4.4.4] Overall adaptive capacity is considered to be low. [22.4.2] Disaster risk reduction, social protection, technological and infrastructural adaptation, ecosystem-based approaches and livelihood diversification are reducing vulnerability, but largely in isolated initiatives. [22.4.5] and most adaptation remain autonomous and reactive to short-term motivations. [22.4.3, 22.4.4.5]

Conservation agriculture provides a viable means for strengthening resilience in agroecosystems and livelihoods that also advance adaptation goals *(high confidence*). A wide array of conservation agriculture practices, including agroforestry and farmer-managed natural tree regeneration, conservation tillage, contouring and terracing, and mulching are being increasingly adopted in Africa. These practices strengthen resilience of the land base to extreme events and broaden sources of livelihoods, both of which have strongly positive implications for climate risk management and adaptation. Moreover, conservation agriculture has direct adaptation-mitigation co-benefits. Addressing constraints to broader adoption of these practices, such as land tenure/usufruct stability, access to peer-to-peer learning, gender-oriented extension and credit and markets, as well as identification of perverse policy incentives would help to enable larger scale transformation of agricultural landscapes. [22.4.5.6, 22.4.5.7, 22.4.6, 22.6.2]

Despite implementation limitations, Africa's adaptation experiences nonetheless highlight valuable lessons for enhancing and scaling up the adaptation response, including principles for good practice and integrated approaches to adaptation (*high confidence*). Five common principles for adaptation and building adaptive capacity can be distilled: (i) supporting autonomous adaptation through policy that recognises the multiple stressor nature of vulnerable livelihoods; (ii) increasing attention to the cultural, ethical, and rights considerations of adaptation by increasing the participation of women, youth and poor and vulnerable people in adaptation policy and implementation; [22.4.5] (iii) combining 'soft path' options and flexible and iterative learning approaches with technological and infrastructural approaches and blending scientific, local and indigenous knowledge when developing adaptation strategies; (iv) focusing on building resilience and implementing low-regrets adaptation with development synergies, in the face of future climate and socio-economic uncertainties; and (v) building adaptive management and social and institutional learning into adaptation processes at all levels. [22.4] Ecosystem-based approaches and pro-poor integrated adaptation-mitigation initiatives hold promise for a more sustainable and system-orientedapproach to adaptation, as does promoting equity goals, key for future resilience, through emphasising gender aspects and highly vulnerable groups such as children. . [22.4.2, 22.4.5.6, 22.6.2, Table 22-5]

Strengthened inter-linkages between adaptation and development pathways and a focus on building resilience would help to counter the current adaptation deficit and reduce future maladaptation risks (*high confidence*). [22.4.3] Development strategies are currently not able to counter current climate risks, as highlighted by the impacts of recent extreme events; national policies that disregard cultural, traditional and context-specific factors can act as barriers to local adaptation; and there is increased knowledge of maladaptation risks from narrowly conceived development interventions and sectoral adaptation strategies that decrease resilience in other sectors or ecosystems. [22.4.4, 22.4.6] Given multiple uncertainties in the African context, successful adaptation will depend upon building resilience. [22.4, 22.5, 22.6] Options for pro-poor adaptation/resilient livelihoods include improved social protection, social services and safety nets; better water and land governance and tenure security over land and vital assets; enhanced water storage, water harvesting and post-harvest services; strengthened civil society and greater involvement in planning; and more attention to urban and peri-urban areas heavily affected by migration of poor people. [22.4.2, 22.4.4, 22.4.5, 22.4.6]

Growing understanding of the multiple interlinked constraints on increasing adaptive capacity is beginning to indicate potential limits to adaptation in Africa (*medium confidence*). Climate change combined with other external changes (environmental, social, political, technological) may overwhelm the ability of people to cope and adapt, especially if the root causes of poverty and vulnerability are not addressed. Evidence is growing for the effectiveness of flexible and diverse development systems that are designed to reduce vulnerability, spread risk, and build adaptive capacity. These points indicate the benefits of new development trajectories that place climate resilience, ecosystem stability, equity and justice at the centre of development efforts. [22.4.6]

There is increased evidence of the significant financial resources, technological support and investment in institutional and capacity development needed to address climate risk, build adaptive capacity and implement robust adaptation strategies (*high confidence*). Funding and technology transfer and support isto both address Africa's current adaptation deficit and to protect rural and urban livelihoods, societies and economies from climate change impacts at different local scales. [22.4,] [22.6.4] Strengthening institutional capacities and governance mechanisms to enhance the ability of national governments and scientific institutions in Africa to absorb and effectively manage large amounts of funds allocated for adaptation, will assure the effectiveness of adaptation initiatives (*medium confidence*). [22.6.4]

Climate change and climate variability have the potential to exacerbate or multiply existing threats to human security including food, health and economic insecurity, all being of particular concern for Africa (*medium confidence*). [22.6.1, 22.6.1.1] Many of these threats are known drivers of conflict (*high confidence*). Causality between climate change and violent conflict is difficult to establish due to the presence of these and other interconnected causes, including country-specific sociopolitical, economic and cultural factors. For example, the degradation of natural resources as a result of both overexploitation and climate change will contribute to increased conflicts over the distribution of these resources. [22.6.1.1] Many of the interacting social, demographic and economic drivers of observed urbanization and migration in Africa are sensitive to climate change impacts. [22.6.1.2]

A wide range of data and research gaps constrain decisionmaking in processes to reduce vulnerability, build resilience and plan and implement adaptation strategies at different levels in Africa (*high confidence)*.

Overarching data and research gaps identified include data management and monitoring of climate parameters and development of climate change scenarios; monitoring systems to address climate change impacts in the different sectors; research and improved methodologies to assess and quantify the impact of climate change on different sectors and systems; and socio-economic consequences of the loss of ecosystems, of economic activities, of certain mitigation choices, such as biofuels, and of adaptation strategies. [22.7]

Of nine climate-related key regional risks identified for Africa, eight pose medium or higher risk even with highly adapted systems, while only one key risk assessed can be potentially reduced with high adaptation to below a medium risk level, for the end of the 21st century under 2°C global mean temperature increase above pre-industrial levels (*medium confidence*). Key regional risks relating to shifts in biome distribution, loss of coral reefs, reduced crop productivity, adverse effects on livestock, vector- and water-borne diseases, undernutrition, and migration are assessed as either medium or high for the present under current adaptation, reflecting Africa's existing adaptation deficit. [22.3.1, 22.3.2, 22.3.4, 22.3.5, 22.6.1.2] The assessment of significant residual impacts in a 2°C world at the end of the 21st century suggests that even under high levels of adaptation, there could be very high levels of risk for Africa. At a global mean temperature increase of 4°C, risks for Africa's food security (see key risks on livestock and crop production) are assessed as very high, with limited potential for risk reduction through adaptation. [22.3.4, 22.4.5, 22.5, Table 22-6]

22.1. Introduction

Africa as a whole is one of the most vulnerable continents due to its high exposure and low adaptive capacity Climate, ecology and political boundaries in Africa vary across the continent. Since the African Union, together with its Regional Economic Communities (RECs), are encharged of the adaptation policies we have used these divisions for regional assessment within the chapter.

22.1.1. Structure of the Regions

The African continent (including Madagascar) is the world's second largest and most populous continent (1,031,084,000 in 2010) behind Asia (UN DESA, 2013). The continent is organized at the regional level under the African Union (AU).[1] The AU's Assembly of Heads of State and Government has officially recognized eight Regional Economic Communities (RECs) (Ruppel, 2009). Except for the Sahrawi Arab Democratic Republic,[2] all AU member states are affiliated with one or more of these RECs. These RECs include the Arab Maghreb Union (AMU), with 5 countries in Northern Africa; the Community of Sahel-Saharan States (CEN-SAD), grouping 27 countries; the Common Market for Eastern and Southern Africa (COMESA), grouping 19 countries in Eastern and Southern Africa; the East African Community (EAC), with 5 countries; the Economic Community of Central African States (ECCAS), with 10 countries; the Economic Community of West African States (ECOWAS), with 15 countries; the Intergovernmental Authority on Development (IGAD) with 8 countries; and the Southern African Development Community (SADC), with 15 countries. The regional subdivision of African countries into REC's is a structure used by the AU and the New Partnership for Africa (NEPAD).

[FOOTNOTE 1: Due to the controversies regarding the Sahrawi Arab Democratic Republic, Morocco withdrew from the Organization of African Unity (OAU) in protest in 1984 and, since South Africa's admittance in 1994, remains the only African nation not within what is now the AU.]

[FOOTNOTE 2: Although the Sahrawi Arab Democratic Republic has been a full member of the OAU since 1984 and remains a member of the AU, the republic is not generally recognized as a sovereign state and has no representation in the UN.]

22.1.2. Major Conclusions from Previous Assessments

22.1.2.1. Regional Special Report and Assessment Reports

Refer to Table 22-1 for a brief summary of conclusions from previous IPCC assessments.

[INSERT TABLE 22-1 HERE
Table 22-1: Major conclusions from previous IPCC assessments.]

22.1.2.2. Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)

The Special Report of the IPCC on managing the risks of extreme events and disasters to advance climate change adaptation (IPCC, 2012) is of particular relevance to the African continent. There is *low* to *medium confidence* in historical extreme temperature and heavy rainfall trends over most of Africa because of partial lack of data, literature and lack of consistency of reported patterns in the literature (Seneviratne *et al.*, 2012). However, most regions within Africa for which data is available have recorded an increase in extreme temperatures (Seneviratne *et al.*, 2012). For projected temperature extreme there is *high confidence* that heat waves and warm spell durations will increase, suggesting an increased persistence of hot days (90^{th} percentile) toward the end of the century (Tebaldi *et al.*, 2006; Orlowsky and Seneviratne, 2012). There is *high confidence* for projected shorter extreme maximum temperature return periods across the B1, A1B and A2 scenarios for the near and far future as well as a reduction of the number of cold extremes (Seneviratne *et al.*, 2012). In East and southern Africa, there is *medium confidence* that droughts will intensify in the 21st Century in some seasons, due to reduced precipitation and/or increased evapotranspiration. There is *low confidence* in projected increases of heavy precipitation over most of Africa except over East Africa where there is a *high confidence* in a projected increase in heavy precipitation (Seneviratne *et al.*, 2012).

22.2. Observed Climate Trends and Future Projections

22.2.1. Temperature

22.2.1.1. Observed Trends

Near surface temperatures have increased by 0.5°C or more during the last 50-100 years over most parts of Africa with minimum temperatures warming more rapidly than maximum temperatures (Hulme *et al.*, 2001; Jones and Moberg, 2003; Kruger and Shongwe, 2004; Schreck and Semazzi, 2004; New *et al.*, 2006; IPCC, 2007; Rosenzweig *et al*., 2007; Trentberth *et al.*, 2007; Christy *et al.*, 2009; Collins 2011; Grab and Craparo, 2011; Hoffman *et al.*, 2011; Mohamed, 2011; Stern *et al.* 2011; Funk *et al*., 2012; Nicholson *et al.*, 2013). Near surface air temperature anomalies in Africa were significantly higher for the period 1995–2010 compared to the period 1979–1994 (Collins, 2011). Figure 22-1 shows that it is *very likely* that mean annual temperature has increased over the past century over most of the African continent, with the exception of areas of the interior of the continent where the data coverage has been determined to be insufficient to draw conclusions about temperature trends (Figure 22-1, Box CC-RC). There is strong evidence of an anthropogenic signal in continent-wide temperature increases in the 20th century (WGI 10.3.1; Stott, 2003; Min and Hense, 2007, Stott *et al.*, 2010; Stott *et al.*, 2011).

In recent decades North African annual and seasonal observed trends in mean near surface temperature indicates an overall warming that is significantly beyond the range of changes due to natural (internal) variability (Barkhordarian *et al*., 2012a). During the warm seasons (March-April-May, June-July-August) an increase in near surface temperature is shown over north Algeria and Morocco which is very unlikely due to natural variability or natural forcing alone (Barkhordarian et al., 2012b). The region has also experienced positive trends in annual minimum and maximum temperature (Vizy and Cook, 2012).

Over West Africa and the Sahel near surface temperatures have increased over the last 50 years. Using indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI), New *et al.* (2006) show the number of cold days and cold nights have decreased and the number of warm days and warm nights have increased between 1961 and 2000. Many of these trends are statistically significant at the 90% level and they find similar trends in extreme temperature indices. Collins (2011) shows statistically significant warming of between 0.5-0.8 degrees between 1970 and 2010 over the region using remotely sensed data with a greater magnitude of change in the latter 20 years of the period compared to the former.

The equatorial and southern parts of eastern Africa have experienced a significant increase in temperature since the beginning of the early 1980s (Anyah and Qiu, 2012). Similarly, recent reports from the Famine Early Warning Systems Network (FEWS NET) indicate that there has been an increase in seasonal mean temperature in many areas of Ethiopia, Kenya, South Sudan, and Uganda over the last 50 years (Funk *et al.*, 2011, 2012). In addition, warming of the near surface temperature and an increase in the frequency of extreme warm events has been observed for countries bordering the western Indian Ocean between 1961 and 2008 (Vincent *et al.*, 2011b).

In recent decades, most of southern Africa has also experienced upward trends in annual mean, maximum, and minimum temperature over large extents of the subregion during the last half of the 20th century, with the most significant warming occurring during the last two decades (Zhou *et al.*, 2010; Collins, 2011; Kruger and Sekele, 2012). Minimum temperatures have increased more rapidly relative to maximum temperatures over inland southern Africa (New *et al.*, 2006).

22.2.1.2. Projected Trends

Temperatures in Africa are projected to rise faster than the global average increase during the 21st Century (Christensen *et al.*, 2007; Joshi *et al.* 2011; Sanderson *et al.*, 2011; James and Washington, 2013). Global average near-surface air temperature are projected to move beyond 20th Century simulated variability by 2069 (±18 years) under RCP4.5 and by 2047 (±14 years) under RCP8.5 (Mora *et al.* 2013). However, in the tropics, especially tropical West Africa, these unprecedented climates are projected to occur one to two decades earlier the global average because the relatively small natural climate variability in this region generates narrow climate bounds that can be easily surpassed by relatively small climate changes. Figure 22-1 shows projected temperature increases based on the CMIP5 ensemble. Increases in mean annual temperature over all land areas are *very likely* in the mid- and late-21st-century periods for RCP2.6 and RCP8.5 (Figure 22-1, Box CC-RC). Ensemble-mean changes in mean annual temperature exceed 2˚C above the late-20th-century baseline over most land areas of the continent in the mid-21st-century for RCP8.5, and exceed 4˚C over most land areas in the late-21st-century for RCP8.5. Changes in mean annual temperature for RCP8.5 follow a pattern of larger changes in magnitude over northern and southern Africa, with (relatively) smaller changes in magnitude over central Africa. The ensemble-mean changes are less than 2˚C above the late-20th-century baseline in both the mid- and late-21st-century for RCP2.6.

Over North Africa under the A1B scenario, both annual minimum and maximum temperature are *likely* to increase in the future, with greater increase in minimum temperature (Vizy and Cook, 2012). The faster increase in minimum temperature is consistent with greater warming at night, resulting in a decrease in the future extreme temperature range (Vizy and Cook, 2012). Higher temperature increases are projected during boreal summer by CMIP5 GCMs (WGI Annex 1). A strengthening of the North African thermal low in 21st century is associated with a surface temperature increase (Paeth *et al.*, 2009; Patricola and Cook, 2010; Barkhordarian *et al.*, 2012a; Cook and Vizy, 2012).

Temperature projections over West Africa for the end of the 21st Century from both the CMIP3 GCMs (A2 and A1B scenarios) and CMIP5 GCMs (RCP4.5 and RCP8.5) range between 3-6°C above the late 20th Century baseline (Meehl *et al.* 2007; Fontaine *et al*. 2011; Diallo *et al.*, 2012; Monrie *et al*. 2012; Figure 22-1; Figure 22-2). Regional downscalings over the region produce a similar range of projected change (Patricola and Cook, 2010; Mariotti *et al.*, 2011; Patricola and Cook, 2011; Vizy *et al*., 2012). Diffenbaugh and Giorgi (2012) identify the Sahel and tropical West Africa as a hotspot of climate change for both RCP4.5 and RCP8.5 pathways and unprecedented climates are projected to occur earliest (late 2030s to early 2040s) in these regions (Mora *et al.*, 2013).

Climate model projections under the A2 and B1 scenarios over Ethiopia show warming in all four seasons across the country, which may cause a higher frequency of heat waves as well as higher rates of evaporation (Conway and Schipper, 2011). Projected maximum and minimum temperatures over equatorial eastern Africa show a significant increase in the number of days warmer than 2°C above the 1981–2000 average by the middle and end of the 21st century under the A1B and A2 scenarios (Anyah and Qiu, 2012). Elshamy *et al*. (2009) show a temperature increase over the upper Blue Nile of between 2°C and 5°C at the end of the 21st Century under the A1B scenario compared to a 1961-1990 baseline.

Mean land surface warming in Southern Africa is *likely* to exceed the global mean land surface temperature increase in all seasons (Sillmann and Roeckner, 2008; Watterson, 2009; Mariotti *et al.*, 2011; James and Washington, 2013; Orlowsky and Seneviratne, 2012). Furthermore, towards the end of the 21st Century the projected warming of between 3.4-4.2ºC above the 1981-2000 average under the A2 scenario far exceeds natural climate variability (Moise and Hudson, 2008). High warming rates are projected over the semi-arid southwestern parts of the subregion covering northwestern South Africa, Botswana, and Namibia (WGI Annex 1; Moise and Hudson, 2008; Engelbrecht *et al.*, 2009; Watterson, 2009; Shongwe *et al.*, 2009). Observed and simulated variations in past and projected future annual average temperature over five African regions (UMA, SADC, ECCAS, ECOWAS, and COMESA) are captured in Figure 22-2 which indicates the projected temperature rise is *very likely* to exceed the 1986-2005 baseline by between 3 and 6 °C across these regions by the end of this century under RCP8.5.

[INSERT FIGURE 22-1 HERE
Figure 22-1: Observed and simulated variations in past and projected future annual average precipitation and temperature. Observed differences in the Climate Research Unit, University of East Anglia data (CRU) are shown between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For CMIP5, white indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Grey indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st Century period is 2081-2100. The mid-21st century period is 2046-2065.]

[INSERT FIGURE 22-2 HERE
Figure 22-2: Observed and simulated variations in past and projected future annual average temperature over EAC-IGAD-Egypt, ECCAS, ECOWAS, SADC and UMA. Black lines show various estimates from observational measurements. Shading denotes the 5-95 percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (63 simulations), historical changes in "natural" drivers only (34), the "RCP2.6" emissions scenario (63), and the "RCP8.5" (63). Data are anomalies from the 1986-2005 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Box 21-3.]

22.2.2. Precipitation

22.2.2.1. Observed Changes

Most areas of the African continent lack sufficient observational data to draw conclusions about trends in annual precipitation over the past century (Figure 22-1, Box CC-RC). Additionally, in many regions of the continent discrepancies exist between different observed precipitation datasets (Nikulin *et al.* 2012; Sylla *et al*., 2012; Kim *et* *al*. 2013; Kalognomou *et al.*, 2013). Areas where there are sufficient data include *very likely* decreases in annual precipitation over the past century over parts of the western and eastern Sahel region in northern Africa, along with *very likely* increases over parts of eastern and southern Africa.

Over the last few decades the northern regions of North Africa (north of the Atlas Mountains and along the Mediterranean coast of Algeria and Tunisia) have experienced a strong decrease in the amount of precipitation received in winter and early spring (Barkhordarian *et al.,* 2013). The observed record also indicates greater than 330 dry days (with less than 1 mm/day rainfall) per year over the 1997 - 2008 time period (Vizy and Cook, 2012). However, in autumn (September, October, November) observations show a positive trend in precipitation in some parts of North Algeria and Morocco (Barkhordarian *et al.*, 2013). The Sahara Desert, which receives less than 25 mm/year, shows little seasonal change (Liebmann *et al*., 2012).

Rainfall over the Sahel has experienced an overall reduction over the course of the 20th Century with a recovery toward the last 20 years of the century (WGI 14.3.7.1; Nicholson *et al.*, 2000; Lebel and Ali, 2009; Ackerley *et al.,* 2011; Mohamed, 2011; Biasutti, 2013). The occurrence of a large number of droughts in the Sahel during the 1970s and 1980s is well documented and understood (Biasutti and Giannini, 2006; Biasutti *et al.*, 2008; Greene *et al.*, 2009). The recovery of the rains may be due to natural variability (Mohino *et al*., 2011) or a forced response to increased greenhouse gases (Haarsma *et al*., 2005; Biasutti, 2013) or reduced aerosols (Ackerley *et al.*, 2011).

Precipitation in eastern Africa shows a high degree of temporal and spatial variability dominated by a variety of physical processes (Rosell and Holmer, 2007; Hession and Moore, 2011). Williams and Funk (2011) and Funk *et al*. (2008) indicate that over the last three decades rainfall has decreased over eastern Africa between March and May/June. The suggested physical link to the decrease in rainfall is the rapid warming of Indian Ocean, which causes an increase in convection and precipitation over the tropical Indian Ocean and thus contributes to increased subsidence over eastern Africa and a decrease in rainfall during March to May/June (Funk *et al.*, 2008; Williams and Funk, 2011). Similarly, Lyon and DeWitt (2012) show a decline in the March–May seasonal rainfall over eastern Africa. Summer (June–September) monsoonal precipitation has declined throughout much of the Great Horn of Africa over the last 60 years [during the 1948–2009 period; Williams *et al.*, (2012)] as a result of the changing sea level pressure (SLP) gradient between Sudan and the southern coast of the Mediterranean Sea and the southern tropical Indian Ocean region (Williams *et al.*, 2012).

Over Southern Africa a reduction in late austral summer precipitation has been reported over its western parts, extending from Namibia, through Angola, and toward the Congo during the second half of the 20th Century (Hoerling *et al.*, 2006; New *et al*., 2006). The drying is associated with an upward trend in tropical Indian Ocean Sea Surface Temperatures (SSTs). Modest downward trends in rainfall are found in Botswana, Zimbabwe, and western South Africa. Apart from changes in total or mean summer rainfall, certain intra-seasonal characteristics of seasonal rainfall such as onset, duration, dry spell frequencies, and rainfall intensity as well as delay of rainfall onset have changed (Tadross *et al.*, 2005; Thomas *et al.*, 2007; Tadross *et al.*, 2009; Kniveton *et al.*, 2009). An increasing frequency of dry spells is accompanied by an increasing trend in daily rainfall intensity which has implications for run-off characteristics (New *et al.*, 2006).

22.2.2.2. Projected Changes

Precipitation projections are more uncertain than temperature projections (Rowell, 2012) and exhibit higher spatial and seasonal dependence than temperature projections (Orlowsky and Seneviratne, 2012). The CMIP5 ensemble projects *very likely* decreases in mean annual precipitation over the Mediterranean region of northern Africa in the mid- and late-21st century periods for RCP8.5 (Figure 22-1, Box CC-RC). CMIP5 also projects *very likely* decreases in mean annual precipitation over areas of southern Africa beginning in the mid-21st-century for RCP8.5 and expanding substantially in the late-21st-century for RCP8.5. In contrast, CMIP5 projects *likely* increases in mean annual precipitation over areas of central and eastern Africa beginning the mid-21st-century for RCP8.5. Most areas of the African continent do not exhibit changes in mean annual precipitation that exceed the baseline variability in more than 66% of the models in either the mid- or late-21st-century periods for RCP2.6. Observed and simulated variations in past and projected future annual average precipitation over five African regions (UMA, ECCAS, ECOWAS, SADC and COMESA) are captured in Figure 22-2.

A reduction in rainfall over northern Africa is *very likely* by the end of the 21st Century. The annual and seasonal drying/warming signal over the Northern African region (including North of Morocco, Algeria, Libya, Egypt and Tunisia) is a consistent feature in the global (Giorgi and Lionello, 2008; Barkhordarian et al., 2013) and the regional (Lionello and Giorgi, 2007; Gao and Giorgi, 2008; Paeth *et al*., 2009; Patricola and Cook, 2010) climate change projections for the 21st Century under the A1B and A2 scenarios. Furthermore, over the northern basin of Tunisia, climate models under the A1B scenario project a significant decrease in the median, and 10th and 90th percentiles values of precipitation in winter and spring seasons (Bargaoui *et al*., 2013).

West African precipitation projections in the CMIP-3 and CMIP-5 archives show inter-model variation in both the amplitude and direction of change that is partially attributed to the inability of GCMs to resolve convective rainfall (WGI 14.8.7; Biasutti *et al.*, 2008; Druyan, 2011; Fontaine *et al*., 2011; Roehrig *et al.*, 2013). Many CMIP-5 models indicate a wetter core rainfall season with a small delay to rainy season by the end of the 21st Century (WGI 14.8.7; Biasutti, 2013). However, regional climate models (RCMs) can alter the sign of rainfall change of the driving GCM especially in regions of high or complex topography (WGI 14.3.7.1; WGI 9.6.4; Sylla *et al.*, 2012; Cook and Vizy, 2013; Saeed *et al.* 2013). There is therefore *low* to *medium confidence* in the robustness of projected regional precipitation change until a larger body of regional results become available through, for example, the coordinated regional downscaling experiment, CORDEX (Giorgi *et al*., 2009, Jones *et al*., 2011, Hewitson *et al.*, 2012).

An assessment of 12 CMIP-3 GCMs over eastern Africa suggest that by the end of the 21st Century there will be a wetter climate with more intense wet seasons and less severe droughts during October-November-December (OND) and March-April-May (MAM) (WGI 14.8.7; Moise and Hudson, 2008; Shongwe *et al.*, 2011). These results indicate a reversal of historical trend in these months (Williams and Funk, 2011; Funk *et al*. 2008). Lyon and DeWitt (2012) ascribe this reversal to recent cooling in the eastern equatorial Pacific that offsets the equatorial Pacific SST warming projected by CMIP3 GCMs in future scenarios. However, GCM projections over Ethiopia indicate a wide range of rainfall spatial pattern changes (Conway and Schipper, 2011) and in some regions GCMs do not agree on the direction of precipitation change, e.g. in the upper Blue Nile basin in the late 21st Century (Elshamy *et al*., 2009). Regional climate model studies suggest drying over most parts of Uganda, Kenya, and South Sudan in August and September by the end of the 21st Century as a result of a weakening Somali jet and Indian monsoon (Patricola and Cook, 2011). Cook and Vizy (2013) indicate truncated boreal spring rains in the mid-21st Century over eastern Ethiopia, Somalia, Tanzania and southern Kenya while the boreal fall season is lengthened in the southern Kenya and Tanzania (Nakaegawa *et al*., 2012). These regional studies highlight the importance of resolving both regional scale atmospheric processes and local effects like land surface on rainfall simulation across the region (WGI 14.8.7).

Over southern Africa CMIP3 GCM projections show a drying signal in the annual mean over the climatologically dry southwest, extending northeastward from the desert areas in Namibia and Botswana (Moise and Hudson, 2008; James and Washington, 2013; Orlowsky and Seneviratne, 2012). This pattern is replicated by CMIP5 GCMs (see Figure 22-1). During the austral summer months, dry conditions are projected in the southwest while downscaled projections indicate wetter conditions in the southeast of South Africa and the Drakensberg mountain range (Hewitson and Crane, 2006; Engelbrecht *et al.*, 2009). Consistent with the AR4, drier winters are projected over a large area in southern Africa by the end of the century as a result of the poleward displacement of mid-latitude storm tracks (WGI 14.8.7; Moise and Hudson, 2008; Engelbrecht *et al.*, 2009; Shongwe *et al.*, 2009; Seth *et al.*, 2011; James and Washington, 2013). Rainfall decreases are also projected during austral spring months, implying a delay in the onset of seasonal rains over a large part of the summer rainfall region of Southern Africa (Shongwe *et al.*, 2009; Seth *et al.*, 2011). The sign, magnitude and spatial extent of projected precipitation changes are dependent on the coupled general circulation model (CGCM) employed, due primarily to parameterization schemes used and their interaction with model dynamics (Hewitson and Crane, 2006; Rocha *et al.*, 2008). Changes in the parameterization schemes of a single regional climate model produced opposite rainfall biases over the region (Crétat *et al*., 2012) so multiple ensemble downscalings, such as those being produced through CORDEX, are important to more fully describe the uncertainty associated with projected rainfall changes across the African continent (WGI 9.6.5; Laprise *et al.*, 2013).

22.2.3. Observed and Projected Changes in Extreme Temperature and Rainfall

In Northern Africa the north western Sahara experienced 40-50 heat wave days per year during the 1989-2009 time period (Vizy and Cook, 2012). There is a projected increase in this number of heat wave days over the 21st century (Patricola and Cook, 2010; Vizy and Cook, 2012).

Over West Africa there is *low* to *medium confidence* in projected changes of heavy precipitation by the end of the 21st Century based on CMIP-3 GCMs (Seneviratne *et al.*, 2012). Regional model studies suggest an increase in the number of extreme rainfall days over West Africa and the Sahel during May and July (Vizy and Cook, 2012) and more intense and more frequent occurrences of extreme rainfall over the Guinea Highlands and Cameroun Mountains (Sylla *et al.*, 2012; Haensler *et al*., 2013. The ability of regional climate models to resolve complex topography captures the amplifying role of topography in producing extreme rainfall that GCMs cannot.

Extreme precipitation changes over Eastern Africa such as droughts and heavy rainfall have been experienced more frequently during the last 30-60 years (Funk *et al.*, 2008; Williams and Funk, 2011; Shongwe *et al.*, 2011; Lyon and DeWitt, 2012). A continued warming in the Indian–Pacific warm pool has been shown to contribute to more frequent East African droughts over the past 30 years during the spring and summer seasons (Williams and Funk, 2011). It is unclear whether these changes are due to anthropogenic influences or multidecadal natural variability (Lyon and DeWitt, 2012; Lyon *et al.*, 2013). Projected increases in heavy precipitation over the region have been reported with high certainty in the SREX (Seneviratne *et al.*, 2012) and Vizy and Cook (2012) indicate an increase in the number of extreme wet days by the mid-20th Century.

Over southern Africa an increase in extreme warm ETCCDI indices (hot days, hot nights, hottest days) and a decrease in extreme cold indices (cold days and cold nights) in recent decades is consistent with the general warming trend (New *et al.*, 2006; Tebaldi *et al.*, 2006; Aguilar et al. 2009; Kruger and Sekele, 2012). The probability of austral summer heat waves over South Africa increased over the last two decades of the 20th century compared to 1961 to 1980 (Lyon, 2009). Enhanced heat wave probabilities are associated with deficient rainfall conditions that tend to occur during El Niño events. The southwestern regions are projected to be at a high risk to severe droughts during the 21st Century and beyond (Hoerling *et al.*, 2006; Shongwe *et al.*, 2011). Large uncertainties surround projected changes in tropical cyclone landfall from the southwest Indian Ocean that have resulted in intense floods during the 20th Century. Future precipitation projections show changes in the scale of the rainfall probability distribution, indicating that extremes of both signs may become more frequent in the future (Kay and Washington, 2008).

22.3. Vulnerability and Impacts

This section highlights Africa's vulnerability to climate change, as well as the main observed and potential impacts on natural resources, ecosystems, and economic sectors. Figure 22-3 summarizes the main conclusions regarding observed changes in regional climate and their relation to anthropogenic climate change (described in 22.2) as well as regarding observed changes in natural and human systems and their relation to observed regional climate change (described in this section). Confidence in detection and attribution of anthropogenically-driven climate change is highest for temperature measures. In many regions of Africa, evidence is constrained by limited monitoring. However, impacts of observed precipitation changes are amongst the observed impacts with the highest assessment of confidence, implying that some of the potentially more significant impacts of anthropogenic climate change for Africa are of a nature that challenges detection and attribution analysis (18.5.1).

[INSERT FIGURE 22-3 HERE
Left: Confidence in detection and in attribution of observed climate change over Africa to anthropogenic emissions. All detection assessments are against a reference of no change, while all attribution assessments concern a major role of anthropogenic emissions in the observed changes. See 22.2, and SREX-3, and WGI AR5 10 for details. Right: Confidence in detection and in attribution of the impacts of observed regional climate change on various African systems. All detection assessments are against a reference of no change, except "Kenyan Highlands malaria"

(changes due to vaccination, drug resistance, demography, and livelihoods), "Great Lakes fisheries" (changes due to fisheries management and land use) and “Adapting South African farmers” (economic changes). Attribution is to a major role or a minor role of observed climate change, as indicated. See 22.2.2, 22.3.2.1, 22.3.2.2, 2.3.3, 22.4.2, 22.3.4.4, 22.3.5.4, 22.4.5.7 and Tables 18-5, 18-6, 18-7, and 18-9 for details. Assessments follow the methods outlined in 18.2.]

22.3.1. Socioeconomic and Environmental Context Influencing Vulnerability and Adaptive Capacity

Equitable socioeconomic development in Africa may strengthen its resilience to various external shocks, including climate change. In 2009, the Human Rights Council adopted Resolution 10/4[3] which noted the effects of climate change on the enjoyment of human rights, and reaffirmed the potential of human rights obligations and commitments to inform and strengthen international and national policy making.

[FOOTNOTE 3: U.N. Doc. A/HRC/10/L.11.]

The impacts of climate change on human rights have been explicitly recognised by the African Commission on Human and Peoples’ Rights (hereafter African Commission) in its Resolution on Climate Change and Human Rights and the Need to Study its Impact in Africa (ACHPR/Res 153 XLV09). The 1981 African (Banjul) Charter on Human and Peoples’ Rights (hereafter African Charter) protects the right of peoples to a ‘general satisfactory environment favorable to their development’ (Article 24). The recognition of this right and the progressive jurisprudence by the African Commission in environmental matters underline the relevance of potential linkages between climate change and human rights (Ruppel, 2012).

The link between climate change and humans is not only associated with human rights. Rather, strong links exist between climate change and the MDGs: climate change may adversely affect progress toward attaining the MDGs, as climate change can increase the pressure not only economic activities, such as agriculture (22.3.4) and fishing (22.3.4.4) but also adversely affect urban areas located in coastal zones (22.3.6). Slow progress in attaining most MDGs may, meanwhile, reduce the resilience and adaptive capabilities of African individuals, communities, states, and nations (ECA *et al.*, 2009, 2012; UNDP *et al*., 2011).

The African continent has made significant progress on some MDGs; however, not all MDGs have been achieved, yet with high levels of spatial and group disparities. Additionally, progress on all MDG indicators is skewed in favor of higher-income groups and urban populations, which means further marginalization of already excluded groups (UN *et al.*, 2008; AfDB *et al.*, 2010; World Bank and IMF, 2010). As a whole, the continent is experiencing a number of demographic and economic constraints, with the population having more than doubled since 1980; exceeding one billion in 2010 and expected to reach three billion by the year 2050, should fertility remain constant (Muchena *et al.*, 2005; Fermont *et al.*, 2008; UN DESA, 2011). The global economic crisis is adding additional constraints on economic development efforts leading to increased loss of livelihood and widespread poverty (Moyo, 2009; Easterly, 2009; Adesina, 2010). The percent of the population below the poverty line has decreased from 56.5% in 1990 to 47.5% in 2008 (excluding North Africa); however a significant proportion of the population living below the poverty line remains chronically poor (ECA *et al.*, 2012). Although poverty in rural areas in Sub-Saharan Africa has declined from 64.9% in 1998 to 61.6% in 2008, it is still double the prevailing average in developing countries in other regions (IFAD, 2010).

Agriculture, which is the main economic activity in terms of employment share, is 98% rain fed in the sub-Saharan region (FAO, 2002). [4] Stagnant agricultural yields, relative to the region’s population growth, have led to a fall in per capita food availability since the 1970s (UN *et al.*, 2008).[5] Such stagnation was reversed with an improved performance of the agricultural sector in sub Saharan Africa during the 2000–2010. However, most of this improvement was the result of countries recovering from the poor performance of the 1980s and 1990s along with favorable domestic prices (Nin-Pratt *et al.*, 2012).

In addition, recent increases in global food prices aggravate food insecurity among the urban poor, increasing the risk of malnutrition and its consequences (UN *et al.*, 2008). For example, it was estimated that the global rise in food prices has contributed to the deaths of an additional 30,000 to 50,000 children suffering from malnutrition in 2009 in sub-Saharan Africa (Friedman and Schady, 2009) see Table 22.2. This situation may be complicated further by changes in rainfall variability and extreme weather events affecting the agriculture sector (Yabi and Afouda, 2012).

In response, the New Partnership for Africa's Development (NEPAD) was founded in 2001, for Africans to take the lead in efforts to achieve the development vision espoused in the AU Constitutive Act as well as the MDGs and to support regional integration as a mechanism for inclusive growth and development in Africa (NEPAD *et al.*, 2012). Furthermore, the Comprehensive Africa Agriculture Development Program (CAADP), which works under the umbrella of NEPAD, was established in 2003 to help African countries reach a higher path of economic growth through agriculture-led development. For this to happen, it focuses on four pillars for action: land and water management, market access, food supply and hunger, and agricultural research (NEPAD, 2010).

[INSERT TABLE 22-2 HERE
Table 22-2: Under-nourishment in Africa, by number and % of total population.]

[FOOTNOTE 4: However, mining and energy sectors, where active, are undergoing expansion, stimulating growth and adding potentially to state revenues but are also highly vulnerable to global recession. overall, the limited production and export structures of the continent are likely to maintain its historical vulnerability to external shocks (ECA and AUC, 2011).]

[FOOTNOTE 5: Lack of extension services for farmers in Africa can also contribute to low utilization and spread of innovations and technologies that can help mitigate climate change.]

Africa has made much progress in the achievement of universal primary education; however, the results are unevenly distributed. Nevertheless, a considerable number of children, especially girls from poor backgrounds and rural communities, still do not have access to primary education (UN *et al.*, 2008).

From the livelihood perspective, African women are vulnerable to the impacts of climate change because they shoulder an enormous but imprecisely recorded portion of the responsibility for subsistence agriculture, the productivity of which can be expected to be adversely affected by climate change and over-exploited soil (Viatte *et al.*, 2009; see also 22.4.2 and Table 22-5).[6] Global financial crises, such as the one experienced in 2007/2008, as well as downturn economic trends at national level, may cause job losses in the formal sector and men may compete for jobs in the informal sector that were previously undertaken by women, making them more vulnerable (AfDB *et al.*, 2010).

[FOOTNOTE 6: For instance, 84% of women in sub-Saharan Africa, compared with 69.5% of men, are engaged in such jobs. In Northern Africa, even though informal or self-employment is less predominant, the gender gap is stark, with much higher proportion of women compared to men are in the more vulnerable informal and self-employed status (56.7% of women compared with 34.9% of men) (UN DESA, 2011).]

Significant efforts have been made to improve access to safe drinking water and sanitation in Africa, with access to safe drinking water increasing from 56 to 65% between 1990 and 2008 (UNDP *et al*., 2011), with sub-Saharan Africa nearly doubling the number of people using an improved drinking water source – from 252 to 492 million over the same period (UN, 2011). Despite such progress, significant disparities in access to safe water and sanitation, between not only urban and rural but also between large- and medium- and small-sized cities, still exist (UNDP *et al.*, 2011). Use of improved sanitation facilities, meanwhile, is generally low in Africa, reaching 41% in 2010 compared to 36% in 1990 (UNDP *et al.*, 2011).

22.3.2. Ecosystems

It is recognized that interactions between the different drivers of ecosystem structure, composition, and function are complex, which makes the prediction of the impacts of climate change more difficult (see Chapter 4). In AR4, the chapter on Africa indicated that extensive pressure is exerted on different ecosystems by human activities (deforestation, forest degradation, biomass utilisation for energy) as well as processes inducing changes such as fires or desertification (see WGII AR4 9.2.2.7). Even if the trend is toward better preservation of ecosystems and a decrease in degradation (like deforestation), pressures linked, for example, to agriculture and food security, energy demand, and urbanization are increasing, putting these ecosystems at risk. This chapter emphasizes new information since AR4 regarding the vulnerability to and impacts of climate change for some terrestrial, fresh water and coastal/ocean ecosystems.

22.3.2.1. Terrestrial Ecosystems

Changes are occurring in the distribution and dynamics of all types of terrestrial ecosystems in Africa, including deserts, grasslands and shrublands, savannas and woodlands, and forests (*high confidence*) (see also 4.3.2.5). Since AR4, three primary trends have been observed at the continental scale. The first is a small overall expansion of desert and contraction of the total vegetated area (Brink and Eva, 2009) (*low confidence*). The second is a large increase in the extent of human influence within the vegetated area, accompanied by a decrease in the extent of natural vegetation (Brink and Eva, 2009; Potapov *et al.*, 2012; Mayaux *et al.*, 2013) (*high confidence*). The third is a complex set of shifts in the spatial distribution of the remaining natural vegetation types, with net decreases in woody vegetation in western Africa (Vincke *et al.*, 2010; Ruelland *et al.*, 2011; Gonzalez *et al.*, 2012) and net increases in woody vegetation in central, eastern, and southern Africa (Wigley *et al*., 2009; Wigley *et al*., 2010; Buitenwerf *et al*., 2012; Mitchard and Flintrop, 2013) (*high confidence*).

Overall, the primary driver of these changes is anthropogenic land use change, particularly the expansion of agriculture, livestock grazing, and fuelwood harvesting (Brink and Eva, 2009; Kutsch *et al*., 2011; Bond and Midgley, 2012; Gonzalez *et al.*, 2012) (*high confidence*). Natural climate variability, anthropogenic climate change, and interactions between these drivers and anthropogenic land use change have important additional and interacting effects (Foden *et al*., 2007; Touchan *et al*., 2008; Brink and Eva, 2009; Bond and Midgley, 2012; Gonzalez *et al.*, 2012) (*high confidence*). Due to these interactions, it has been difficult to determine the role of climate change in isolation from the other drivers (Malhi *et al*., 2013). In general, while there are already many examples of changes in terrestrial ecosystems that are consistent with a climate change signal and have been detected with *high confidence*, attribution to climate change has tended to be characterized by *low confidence* [see Table 22-3]. New observations and approaches are improving confidence in attribution (*e.g.*, Buitenwerf *et al*., 2012, Gonzalez *et al.*, 2012, Pettorelli *et al.*, 2012, Otto *et al*., 2013).

There is *high agreement* that continuing changes in precipitation, temperature, and CO_2 associated with climate change are *very likely* to drive important future changes in terrestrial ecosystems throughout Africa (*high confidence*) [see examples in 4.3.3.1, 4.3.3.2]. Modeling studies focusing on vegetation responses to climate have projected a variety of biome shifts, primarily related to the extent of woody vegetation (Delire *et al.*, 2008; Gonzalez *et al.*, 2010; Bergengren *et al.*, 2011; Zelazowski *et al.*, 2011; Midgley, 2013). For an example of such projections, see Figure 22-4. However, substantial uncertainties are inherent in these projections because vegetation across much of the continent is not deterministically driven by climate alone (*high confidence*). Advances in understanding how vegetation dynamics are affected by fire, grazing, and the interaction of fire and grazing with climate are expected to enable more sophisticated representations of these processes in coupled models (Scheiter and Higgins, 2009; Staver *et al*., 2011a; Staver *et al*., 2011b). Improvements in forecasting vegetation responses to climate change should reduce the uncertainties that are currently associated with vegetation feedbacks to climate forcing, as well as the uncertainties about impacts on water resources, agriculture, and health (Alo and Wang, 2008; Sitch *et al.*, 2008) [see 4.5].

[INSERT FIGURE 22-4 HERE
Figure 22-4: Left – Projected biome change from the periods 1961-1990 to 2071-2100 using the MC1 Dynamic Vegetation Model. Change is indicated if any of nine combinations of three GCMs (CSIRO Mk3, HadCM3, MIROC 3.2 medres) and three emissions scenarios (B1, A1B, A2) project change and is thus a worst-case scenario. Colours represent the future biome predicted. Right – Vulnerability of ecosystems to biome shifts based on historical climate (1901-2002) and projected vegetation (2071-2100), where all nine GCM-emissions scenario combinations agree on the projected biome change. Source: Gonzalez et al. (2010).]

22.3.2.2. Freshwater Ecosystems

Freshwater ecosystems in Africa are at risk from anthropogenic land use change, over-extraction of water and diversions from rivers and lakes, and increased pollution and sedimentation loading in water bodies (Vörösmarty *et al*., 2005; Vié *et al.*, 2009; Darwall *et al.*, 2011). Climate change is also beginning to affect freshwater ecosystems (see also Chapter 3.5.2.4, as evident by elevated water temperatures reported in surface waters of Lakes Kariba, Kivu, Tanganyika, Victoria, and Malawi (Odada *et al.*, 2006; Verburg and Hecky, 2009; Marshall *et al.*, 2009; Hecky *et al.*, 2010; Magadza, 2010; Tierney *et al.*, 2010; Olaka *et al.*, 2010; Magadza, 2011; Ndebele-Murisa, 2011; Woltering *et al.*, 2011; Osborne, 2012; Ndebele-Murisa *et al.*, 2012) (*medium confidence*).

Small variations in climate cause wide fluctuations in the thermal dynamics of freshwaters (Odada *et al.*, 2006; Stenuite *et al.*, 2007; Verburg and Hecky, 2009; Moss, 2010; Olaka *et al.*, 2010). Thermal stratification in the regions' lakes, for instance, isolates nutrients from the euphotic zone, and is strongly linked to hydrodynamic and climatic conditions (Sarmento *et al.*, 2006; Ndebele-Murisa *et al.*, 2010). Moderate warming may be contributing to reduced lake water inflows and therefore nutrients, which subsequently destabilizes plankton dynamics and thereby adversely affects food resources for higher trophic levels of mainly planktivorous fish (*low confidence*) (Magadza, 2008; Verburg and Hecky, 2009; Magadza, 2010; Ndebele-Murisa *et al.*, 2011). However, the interacting drivers of fisheries decline in African lakes are uncertain, given the extent to which other factors, such as overfishing, pollution, and invasive species also impact lake ecosystems and fisheries production (Phoon *et al*., 2004; Sarvala *et al*., 2006; Verburg *et al*., 2007; Tumbare, 2008; Hecky *et al*., 2010; Marshall, 2012).

22.3.2.3. Coastal and Ocean Systems

Coastal and ocean systems are important for the economies and livelihoods of African countries, and climate change will increase challenges from existing stressors, such as overexploitation of resources, habitat degradation, loss of biodiversity, salinization, pollution, and coastal erosion (Arthurton *et al.*, 2006; UNEP and IOC-UNESCO, 2009; Diop *et al.*, 2011). Coastal systems will experience impacts through sea level rise. They will also experience impacts through high sea levels combined with storm swells, for example as observed in Durban in March 2007, when a storm swell up to 14 m due to winds generated by a cyclone combined with a high astronomic tide at 2.2 m, leading to damages estimated at US$ 100 million (Mather and Stretch, 2012). Other climate change impacts (such as flooding of river deltas or an increased migration toward coastal towns due to increased drought induced by climate change (Rain *et al.*, 2011) will also affect coastal zones.

Some South African sea bird species have moved farther south over recent decades, but land use change may also have contributed to this migration (Hockey and Midgley, 2009; Hockey *et al.*, 2011). However, it is considered that South African seabirds could be a valuable signal for climate change, particularly of the changes induced on prey species related to changes in physical oceanography, if we are able to separate the influences of climate parameters from other environmental ones (Crawford and Altwegg, 2009).

Upwellings, including Eastern Boundary Upwelling Ecosystems (EUBEs) and Equatorial Upwelling Systems (EUSs) are the most biologically active systems in the Oceans (Box CC-UP). In addition to equatorial upwelling, the primary upwelling systems that affect Africa are the Benguela and Canary currents along the Atlantic coast (both EBUEs).The waters of the Benguela current have not shown warming over the period 1950-2009 (30.5.5.1.2), whereas most observations suggest that the Canary current has warmed since the early 1980s, and there is *medium evidence* and *agreement* that primary production in the Canary current has decreased over the past two decades (30.5.5.1.1). Changing temperatures in the Canary current has resulted in changes to important fisheries species (e.g., Mauritanian waters have become increasingly suitable for *Sardinella aurita*) (30.5.5.1.1). Upwellings are areas of naturally low pH and high CO_2 concentrations, and, consequently, may be vulnerable to ocean acidification and its impacts (Box CC-OA, Box CC-UP, 30.5.5). Warming is projected to continue in the Canary current, and the synergies between this increase in water temperature and ocean acidification could influence a number of biological processes (30.5.5.2). Regarding the Benguela current upwelling, there is *medium agreement* despite *limited evidence* that the Benguela system will experience changes in upwelling intensity as a result of climate change (30.5.5.1.2). There is considerable debate as to whether or not climate change will drive an intensification of upwelling (e.g. Bakun *et al.*, 2010; Narayan *et al.*, 2010) in all regions. Discussion of the various hypotheses for how climate change may affect coastal upwelling is presented in Box 30-1.

Ocean acidification (OA) is the term used to describe the process whereby increased CO_2 in the atmosphere, upon absorption, causes lowering of the pH of seawater (CC-OA). Projections indicate that severe impairment of reef accretion by organisms such as corals (Hoegh-Guldberg *et al.*, 2007) and coralline algae (Kuffner *et al.*, 2008) are substantial potential impacts of ocean acidification, and the combined effects of global warming and ocean acidification have been further demonstrated to lower both coral reef productivity (Anthony *et al.*, 2008) and resilience (Anthony *et al.*, 2011). These effects will have consequences for reef biodiversity, ecology, and ecosystem services (6.3.1, 6.3.2, 6.3.5, 6.4.1, 30.3.2, Box CC-CR).

Coral vulnerability to heat anomalies is high in the Western Indian Ocean (30.5.6.1.2). Corals in the southwestern Indian Ocean (Comoros, Madagascar, Mauritius, Mayotte, Réunion and Rodrigues) appeared to be more resilient than those in eastern locations (30.5.6.1.2). Social adaptive capacity to cope with such change varies, and societal responses (such as closures to fishing) can have a positive impact on reef recovery, as observed in Tanzania (McClanahan *et al.*, 2009). In Africa, fisheries mainly depend on either coral reefs (on the eastern coast) or coastal upwelling (on the western coast). These two ecosystems will be affected by climate change through ocean acidification, a rise in sea surface temperatures, and changes in upwelling (see Box CC-OA, Box CC-CR, Box CC-UP).

[INSERT TABLE 22-3
Table 22-3: Examples of detected changes in species, natural ecosystems, and managed ecosystems in Africa that are both consistent with a climate change signal and published since the AR4. Confidence in detection of change is based on the length of study, and the type, amount and quality of data in relation to the natural variability in the particular species or system. Confidence in the role of climate being a major driver of the change is based on the extent to which the detected change is consistent with that expected under climate change, and to which other confounding or interacting non-climate factors have been considered and been found insufficient to explain the observed change.]

22.3.3. Water Resources

Knowledge has advanced since the AR4 regarding current drivers of water resource abundance in Africa, and in understanding of potential future impacts on water resources from climate change and other drivers. However, inadequate observational data in Africa remains a systemic limitation with respect to fully estimating future freshwater availability (Neumann *et al.*, 2007; Batisani, 2011). Detection of and attribution to climate change are difficult given that surface and groundwater hydrology are governed by multiple, interacting drivers and factors, such as land use change, water withdrawals, and natural climate variability (see also Chapter 3.2.1 and Box CC-WE). There is poor understanding in Africa of how climate change will affect water quality. This is an important knowledge gap.

A growing body of literature generated since the AR4 suggests that climate change in Africa will have an overall modest effect on future water scarcity relative to other drivers, such as population growth, urbanization, agricultural growth, and land use change (*high confidence)* (Alcamo *et al.*, 2007; Carter and Parker, 2009; MacDonald *et al.*, 2009; Taylor *et al.*, 2009; Calow and MacDonald, 2009; Abouabdillah *et al.*, 2010; Beck and Bernauer, 2011; Droogers *et al.*, 2012; Notter *et al.*, 2012; Tshimanga and Hughes, 2012). However, broad-scale assumptions about drivers of future water shortages can mask significant sub-regional variability of climate impacts, particularly in water-stressed regions that are projected to become drier, such as northern Africa and parts of southern Africa. For example, rainfed agriculture in northern Africa is highly dependent on winter precipitation and would be negatively impacted if total precipitation and the frequency of wet days declines across North Africa as has been indicated in recent studies (Born *et al.*, 2008; Driouech *et al.*, 2010; Abouabdillah *et al.*, 2010; García-Ruiz *et al.*, 2011). Similarly, climate model predictions based on average rainfall years do not adequately capture interannual and interdecadal variability that can positively or negatively influence surface water runoff (Beck and Bernauer, 2011; Notter *et al.*, 2012; Wolski *et al.*, 2012). Key challenges for estimating future water abundance in Africa lie in better understanding relationships between evapotranspiration, soil moisture, and land use change dynamics under varying temperature and precipitation projections (Goulden *et al.*, 2009a) and to understand how compound risks such as heat waves and seasonal rainfall variability might interact in the future to impact water resources.

Several studies from Africa point to a future decrease in water abundance due to a range of drivers and stresses, including climate change in Southern and northern Africa (*medium confidence*). For example, all countries within the Zambezi River Basin could contend with increasing water shortages (A2 scenario) although non-climate drivers (e.g., population and economic growth, expansion of irrigated agriculture, and water transfers) are expected to have a strong influence on future water availability in this basin (Beck and Bernauer, 2011). In Zimbabwe, climate change is estimated to increase water shortages for downstream users dependent on the Rozva dam (Ncube *et al.*, 2011). Water shortages are also estimated for the Okavango Delta, from both climate change and increased water withdrawals for irrigation (Murray-Hudson *et al.*, 2006; Milzow *et al.*, 2010; Wolski *et al.*, 2012), and the Breede River in South Africa (Steynor *et al.*, 2009). For North Africa, Droogers *et al.* (2012) estimated that in 2050 climate change will account for 22% of future water shortages in the region while 78% of increased future water shortages can be attributed to socioeconomic factors. Abouabdillah *et al.* (2010) estimated that higher temperatures and declining rainfall (A2 and B1 scenarios) would reduce water resources in Tunisia. Reduced snowpack in the Atlas Mountains from a combination of warming and reduced precipitation, combined with more rapid springtime melting is expected to reduce supplies of seasonal meltwater for lowland areas of Morocco (García-Ruiz *et al.*, 2011).

In Eastern Africa, potential climate change impacts on the Nile Basin are of particular concern given the basin's geopolitical and socioeconomic importance. Reduced flows in the Blue Nile are estimated by late century due to a combination of climate change (higher temperatures and declining precipitation) and upstream water development for irrigation and hydropower (Elshamy *et al.*, 2009; McCartney and Menker Girma, 2012). Beyene *et al.* (2010) estimated that streamflow in the Nile River will increase in the medium term (2010–2039) but will decline in the latter half of this century (A2 and B1 scenarios) as a result of both declining rainfall and increased evaporative demand, with subsequent diminution of water allocation for irrigated agriculture downstream from the High Aswan Dam. Kingston and Taylor (2010) reached a similar conclusion about an initial increase followed by a decline in surface water discharge in the Upper Nile Basin in Uganda. Seasonal runoff volumes in the Lake Tana Basin are estimated to decrease by the 2080s under the A2 and B2 scenarios (Abdo *et al.*, 2009), while Taye *et al.* (2011) reported inconclusive findings as to changes in runoff in this basin. The Mara, Nyando, and Tana rivers in Eastern Africa, are projected to have increased flow in the second half of this century (Taye *et al.*, 2011; Dessu and Melesse, 2012; Nakaegawa *et al*., 2012)).

Estimating the influence of climate change on water resources in West Africa is limited by the significant climate model uncertainties with regards to the region's future precipitation. For example, Itiveh and Bigg (2008) estimate higher future rainfall in the Niger River Basin (A1, A2 and B1 scenarios), whereas Oguntunde and Abiodun (2013) report a strong seasonal component with reduced precipitation in the basin during the rainy season and increased precipitation during the dry season (A1B scenario). The Volta Basin is projected to experience a slight mean increase in precipitation (Kunstmann *et al.*, 2008), and the Bani River Basin in Mali is estimated to experience substantial reductions in runoff (A2 scenario) due to reduced rainfall (Ruelland *et al.*, 2012). The impact of climate change on total runoff in the Congo Basin is estimated to be minimal (A2 scenario) (Tshimanga and Hughes, 2012). Continental wide studies (e.g. De Wit and Stankiewicz, 2006) indicate that surface drainage in dry areas is more sensitive to, and will be more adversely affected by, reduced rainfall than would surface drainage in wetter areas that experience comparable rainfall reductions.

The overall impact of climate change on groundwater resources in Africa is expected to be relatively small in comparison with impacts from non-climatic drivers such as population growth, urbanization, increased reliance on irrigation to meet food demand, and land use change (Calow and MacDonald, 2009; Carter and Parker, 2009; MacDonald *et al.*, 2009; and Taylor *et al.*, 2009). Climate change impacts on groundwater will vary across climatic zones. (See also Chapter 3.4.6). An analysis by MacDonald *et al.* (2009) indicated that changes in rainfall would not be expected to impact the recharge of deep aquifers in areas receiving below 200 mm rainfall per year, where recharge is negligible due to low rainfall. Groundwater recharge may also not be significantly affected by climate change in areas that receive more than 500 mm per year, where sufficient recharge would remain even if rainfall diminished, assuming current groundwater extraction rates. By contrast, areas receiving between 200 to 500 mm per year, including the Sahel, the Horn of Africa, and southern Africa, may experience a decline in groundwater recharge with climate change to the extent that prolonged drought and other precipitation anomalies becomes more frequent with climate change, particularly in shallow aquifers, which respond more quickly to seasonal and yearly changes in rainfall than do deep aquifers (Barthel *et al.*, 2009).

Coastal aquifers are additionally vulnerable to climate change because of high rates of groundwater extraction, which leads to saltwater intrusion in aquifers, coupled with increased saltwater ingression resulting from sea level rise (Moustadraf *et al.*, 2008; Bouchaou *et al.*, 2008; Al-Gamal and Dodo, 2009; Kerrou *et al.*, 2010). Some studies have shown additional impacts of sea level rise on aquifer salinization with salinity potentially reaching very high levels (Carneiro *et al.*, 2010; Niang *et al.*, 2010; Research Institute for Groundwater, 2011). Although these effects are expected to be localized, in some cases they will occur in densely populated areas (Niang *et al.*, 2010). The profitability of irrigated agriculture in Morocco is expected to decline (under both B1 and A1B scenarios) due to increased pumping of groundwater and increased salinization risk for aquifers (Heidecke and Heckelei, 2010).

The capacity of groundwater delivery systems to meet demand may take on increasing importance with climate change (Calow and MacDonald, 2009). For example, where groundwater pumping and delivery infrastructure is poor, and the number of point sources limited, prolonged pumping can lead to periodic drawdowns and increased failure of water delivery systems or increased saline intrusion (Moustadraf *et al.*, 2008). To the extent that drought conditions become more prevalent in Africa with climate change, stress on groundwater delivery infrastructures will increase.

Future development of groundwater resources to address direct and indirect impacts of climate change, population growth, industrialization, and expansion of irrigated agriculture, will require much more knowledge of groundwater resources and aquifer recharge potentials than currently exists in Africa. Observational data on groundwater resources in Africa are extremely limited and significant effort needs to be expended to assess groundwater recharge potential across the continent (Taylor *et al.*, 2009). A preliminary analysis by MacDonald et al. (2012) indicates that total groundwater storage in Africa is 0.66 million km^3, which is “more than 100 times the annual renewable freshwater resources, and 20 times the freshwater stored in African lakes.” However, borehole yields are variable and in many places water yields are relatively low. Detailed analysis of groundwater conditions for water resource planning would need to consider these constraints.

22.3.4. Agriculture and Food Security

Africa’s food production systems are among the world’s most vulnerable because of extensive reliance on rainfed crop production, high intra- and inter-seasonal climate variability, recurrent droughts and floods that affect both crops and livestock, and persistent poverty that limits the capacity to adapt (Boko *et al.*, 2007). In the near term, better managing risks associated with climate variability may help to build adaptive capacities for climate change (Washington *et al.*, 2006; Cooper *et al.*, 2008; Funk *et al.*, 2008). However, agriculture in Africa will face significant challenges in adapting to climate changes projected to occur by mid-century, as negative effects of high temperatures become increasingly prominent under an A1B scenario (Battisti and Naylor, 2009; Burke *et al.*, 2009a), thus increasing the likelihood of diminished yield potential of major crops in Africa (Schlenker and Lobell, 2010; Sultan et al., 2013). Changes in growing season length are possible, with a tendency towards reduced growing season length (Thornton *et al.*, 2011), though with potential for some areas to experience longer growing seasons (Cook and Vizy, 2012). The composition of farming systems from mixed crop-livestock to more livestock dominated food production may occur as a result of reduced growing season length for annual crops and increases in the frequency and prevalence of failed seasons (Jones and Thornton, 2009; Thornton *et al.*, 2010). Transition zones, where livestock keeping is projected to replace crop cultivation by 2050, include the West African Sahel and coastal and mid-altitude areas in eastern and southeastern Africa (Jones and Thornton, 2009), areas that currently support 35 million people and are chronically food insecure.

22.3.4.1. Crops

Climate change is *very likely* to have an overall negative effect on yields of major cereal crops across Africa, with strong regional variability in the degree of yield reduction (see also Chapter 7.3.2.1) (Lobell *et al.*, 2008; Liu *et al.*, 2008; Walker and Schulze, 2008; Thornton *et al.*, 2009a; Lobell *et al.*, 2011; Roudier *et al.*, 2011; Berg *et al.*, 2013) (*high confidence*). One exception is in eastern Africa where maize production could benefit from warming at sites above roughly 1,700 m in elevation (A1FI scenario) (Thornton *et al.*, 2009a), although the majority of current maize production occurs at lower elevations thereby implying a potential change in the distribution of maize cropping. Maize-based systems, particularly in southern Africa, are among the most vulnerable to climate change (Lobell *et al.*, 2008). Estimated yield losses at mid-century range from 18% for southern Africa (Zinyengere *et al.*, 2013) to 22% aggregated across SSA, with yield losses for South Africa and Zimbabwe in excess of 30% (Schlenker and Lobell, 2010). Simulations that combine all regions south of the Sahara suggest consistently negative effects of climate change on major cereal crops in Africa, ranging from 2% for sorghum to 35% for wheat by 2050 under an A2 scenario (Nelson *et al.*, 2009). Studies in North Africa by Eid *et al.*, 2007; Hegazy *et al.*, 2008; Drine, 2011; Mougou *et al.*, 2011 also indicate a high vulnerability of wheat production to projected warming trends. In West Africa, temperature increases above 2° C (relative to a 1961-1990 baseline) are estimated to counteract positive effects on millet and sorghum yields of increased precipitation (for B1, A1B and A2 scenarios) (Figure 22.5), with negative effects stronger in the savannah than in the Sahel, and with modern cereal varieties compared with traditional ones (Sultan et al., 2013).

Several recent studies since the AR4 indicate that climate change will have variable impacts on non-cereal crops, with both production losses and gains possible (*low confidence*). Cassava yields in eastern Africa are estimated to moderately increase up to the 2030s assuming CO2 fertilization and under a range of low to high emissions scenarios (Liu *et al.*, 2008), findings that were similar to Lobell et al. (2008). Suitability for growing cassava is estimated to increase with the greatest improvement in suitability in eastern and central Africa (A1B scenario) (Jarvis *et al.*, 2012). However, Schlenker and Lobell (2010) estimated negative impacts from climate change on cassava at mid-century, although with impacts estimated to be less than those for cereal crops. Given cassava's hardiness to higher temperatures and sporadic rainfall relative to many cereal crops, it may provide a potential option for crop substitution of cereals as an adaptation response to climate change (Rosenthal and Ort, 2012; Jarvis *et al.*, 2012). Bean yields in Eastern Africa are estimated to experience yield reductions by the 2030s under an intermediate emissions scenario (A1B) (Jarvis *et al.*, 2012) and by the 2050s under low (B1) and high (A1FI) emissions scenarios (Thornton *et al.*, 2011). For peanuts, some studies indicate a positive effect from climate change (A2 and B2 scenarios) (Tingem and Rivington, 2009) and others a negative one (Lobell *et al.*, 2008; Schlenker and Lobell, 2010). Bambara groundnuts (*Vigna subterranea*) are estimated to benefit from moderate climate change (Tingem and Rivington, 2009) (A2 and B2 scenarios) although the effect could be highly variable across varieties (Berchie *et al.*, 2012). Banana and plantain production could decline in West Africa and lowland areas of East Africa, whereas in highland areas of East Africa it could increase with temperature rise (Ramirez *et al.*, 2011). Much more research is needed to better establish climate change impacts on these two crops.

Suitable agro-climatic zones for growing economically important perennial crops are estimated to significantly diminish, largely due to the effects of rising temperatures (Läderach *et al.*, 2010; Eitzinger *et al.*, 2011a; Läderach *et al.*, 2011a; Eitzinger *et al.*, 2011b; Läderach *et al.*, 2011b; Läderach *et al.*, 2011c). Under an A2 scenario, by mid-century suitable agro-climatic zones that are currently classified as very good to good for perennial crops may become more marginal, and what are currently marginally suitable zones may become unsuitable; the constriction of crop suitability could be severe in some cases (Table 22-4). Movement of perennial crops to higher altitudes would serve to mitigate the loss of suitability at lower altitudes but this option is limited. Loss of productivity of high-value crops such as tea, coffee and cocoa would have detrimental impacts on export earnings.

[INSERT TABLE 22-4 HERE
Table 22-4. Projected changes in agro-climatic suitability for perennial crops in Africa by mid-century under an A2 scenario.]

[INSERT FIGURE 22-5 HERE
Figure 22-5: The effect of rainfall and temperature changes on mean crop yield. Mean crop yield change (%) relative to the 1961–90 baseline for 7 temperatures (x-axis) and 5 rainfall (y-axis) scenarios. Results are shown as the average over the 35 stations across West Africa and the 6 cultivars of sorghum and millet. White triangles and circles are the projected anomalies computed by several CMIP3 GCMs and three IPCC emission scenarios (B1, A1B, A2) for 2071–90 and 2031–50, respectively. Projections from CMIP5 GCMs and three RCPs (4.5, 6.0 and 8.5) are represented by grey triangles and circles. Models and scenarios names are displayed in figure S2 (available atstacks.iop.org/ERL/8/014040/mmedia). Past observed climate anomalies from CRU data are also projected by computing 10-year averages (e.g. '1940' is for 1941–50). All mean yield changes are significant at a 5% level except boxes with a diagonal line. Source: Sultan et al., 2013.].

22.3.4.2. Livestock

Livestock systems in Africa face multiple stressors that can interact with climate change and variability to amplify the vulnerability of livestock-keeping communities. These stressors include rangeland degradation, increased variability in access to water, fragmentation of grazing areas, sedentarization, changes in land tenure from communal towards private ownership, in-migration of non-pastoralists into grazing areas, lack of opportunities to diversify livelihoods, conflict and political crisis, weak social safety nets, and insecure access to land, markets, and other resources (Solomon *et al.*, 2007; Smucker and Wisner, 2008; Galvin, 2009; Thornton *et al.*, 2009b; Dougill *et al.*, 2010; Ifejika Speranza, 2010). (See also Chapter 7.3.2.4.)

Loss of livestock under prolonged drought conditions is a critical risk given the extensive rangeland in Africa that is prone to drought. Regions that are projected to become drier with climate change, such as Northern and Southern Africa, are of particular concern (Solomon *et al.*, 2007; Masike and Urich, 2008; Thornton *et al.*, 2009b; Dougill *et al.*, 2010; Freier *et al.*, 2012; Schilling *et al.*, 2012). Adequate provision of water for livestock production could become more difficult under climate change. For example, Masike and Urich (2009) estimated that the cost of supplying livestock water from boreholes in Botswana will increase by 23% by 2050 under an A2 scenario due to increased hours of groundwater pumping needed to meet livestock water demands under warmer and drier conditions. Although small in comparison to the water needed for feed production, drinking water provision for livestock is critical, and can have a strong impact on overall resource use efficiency in warm environments (Peden *et al.*, 2009; van Breugel *et al.*, 2010; Descheemaeker *et al.*, 2010; Descheemaeker *et al.*, 2011). Livestock production will be indirectly affected by water scarcity through its impact on crop production and subsequently the availability of crop residues for livestock feeding. Thornton et al. (2010) estimated that maize stover availability per head of cattle will decrease in several East African countries by 2050.

The extent to which increased heat stress associated with climate change will affect livestock productivity has not been well established, particularly in the tropics and sub-tropics (Thornton *et al.*, 2009b), although a few studies point to the possibility that keeping heat-tolerant livestock will become more prevalent in response to warming trends. For example, higher temperatures in lowland areas of Africa could result in reduced stocking of dairy cows in favor of cattle (Kabubo-Mariara, 2008), a shift from cattle to sheep and goats (Kabubo-Mariara, 2008; Seo and Mendelsohn, 2008), and decreasing reliance on poultry (Seo and Mendelsohn, 2008). Livestock keeping in highland areas of East Africa, which is currently cold-limited, would potentially benefit from increased temperatures (Thornton *et al.*, 2010). Lunde and Lindtjørn (2013) challenge a finding in the AR4 that there is direct proportionality between range-fed livestock numbers and changes in annual precipitation in Africa. Their analysis indicates that this relationship may hold in dry environments but not in humid ones.

22.3.4.3. Agricultural Pests, Diseases, and Weeds

Since the AR4, understanding of how climate change will potentially affect crop and livestock pests and diseases and agricultural weeds in Africa is beginning to emerge. Climate change in interaction with other environmental and production factors could intensify damage to crops from pests, weeds and diseases (7.3.2.3).

Warming in highland regions of eastern Africa could lead to range expansion of crop pests into cold-limited areas (*low confidence*). For example, in highland arabica coffee-producing areas of eastern Africa, warming trends may result in the coffee berry borer (*Hypothenemus hampei*) becoming a serious threat in coffee-growing regions of Ethiopia, Kenya, Uganda, Rwanda, and Burundi (Jaramillo *et al.*, 2011). Temperature increases in highland banana-producing areas of eastern Africa enhance the risk of altitudinal range expansion of the highly destructive burrowing nematode, *Radopholus similis* (Nicholls *et al.*, 2008); however, no detailed studies have assessed this risk. Ramirez et al. (2011) estimated that increasing minimum temperatures by 2020 would expand the suitable range of Black Leaf Streak disease (Mycosphaerella fijiensis M.) of banana in Angola and Guinea.

Climate change may also affect the distribution of economically important pests in lowland and dryland areas of Africa (*low confidence*). Under A2A and B2A for 2020, Cotter et al. (2012) estimated that changes in temperature, rainfall, and seasonality will result in more suitable habitats for *Striga hermonthica* in central Africa, whereas the Sahel region may become less suitable for this weed. Striga weed infestations are a major cause of cereal yield reduction in Sub-Saharan Africa. Climate change could also lead to an overall decrease in the suitable range of major cassava pests – whitefly, cassava brown streak virus, cassava mosaic geminivirus, and cassava mealybug (Jarvis *et al.*, 2012), although southeast Africa and Madagascar is estimated to experience increased suitability for cassava pests (Bellotti *et al.*, 2012).

In the case of livestock, Olwoch et al. (2008) estimated that the distribution of the main tick vector species (*Rhipicephalus appendiculatus*) of East Coast fever disease in cattle could be altered by a 2°C temperature increase over mean annual temperatures throughout the 1990s, and changes in mean precipitation resulting in the climatically suitable range of the tick shifting southward. However, a number of environmental and socio-economic factors (e.g., habitat destruction, land use and cover change, and host density) in addition to climatic ones influence tick distribution and need to be considered in assigning causality (Rogers and Randolph, 2006).

22.3.4.4. Fisheries

Fisheries are an important source of food security in Africa. Capture fisheries (marine and inland) and aquaculture combined contribute over one-third of Africa's animal protein intake (Welcomme, 2011), while in some coastal countries fish contribute up to two-thirds of total animal protein intake (Allison *et al.*, 2009). Demand for fish is projected to increase substantially in Africa over the next few decades (De Silva and Soto, 2009). To meet fish food demand by 2020, De Silva and Soto (2009) estimated that aquaculture production in Africa would have to increase nearly 500%.

The vulnerability of national economies to climate change impacts on fisheries can be linked to exposure to the physical effects of climate change, the sensitivity of the country to impacts on fisheries, and adaptive capacity within the country (Allison *et al.*, 2009). In an analysis of fisheries in 132 countries Allison et al. (2009) estimated that two-thirds of the most vulnerable countries were in Africa. Among these countries, the most vulnerable were Angola, DR Congo, Mauritania and Senegal, due to the importance of fisheries to the poor and the close link between climate variability and fisheries production. Coastal countries of West Africa will experience a significant negative impact from climate change. Lam et al. (2012) projected that by 2050 (under an A1B scenario) the annual landed value of fish for that region is estimated to decline by 21%, resulting in a nearly 50% decline in fisheries-related employment and a total annual loss of US$ 311 million to the region's economy.

22.3.4.5. Food Security

Food security in Africa faces multiple threats stemming from entrenched poverty, environmental degradation, rapid urbanization, high population growth rates, and climate change and variability. The intertwined issues of markets and food security have emerged as an important issue in Africa and elsewhere in the developing world since the AR4. Price spikes for globally traded food commodities in 2007–2008 and food price volatility and higher overall food prices in subsequent years have undercut recent gains in food security across Africa (Brown *et al.*, 2009; Hadley *et al.*, 2011; Mason *et al.*, 2011; Tawodzera, 2011; Alem and Söderbom, 2012; Levine, 2012). Among the most affected groups are the urban poor, who typically allocate more than half of their income to food purchases (Cohen and Garrett, 2010; Crush and Frayne, 2010). The proportion of smallholder farmers that are net food buyers of staple grains exceeds 50% in Mozambique, Kenya and Ethiopia (Jayne et al., 2006), thus food security of rural producers is also sensitive to food spikes, particularly in the case of female-headed households, which generally have fewer assets than male-headed households (Kumar and Quisumbing, 2011). Although the recent spike in global food prices can be attributed to a convergence of several factors, the intensification of climate change impacts could become more important in the future in terms of exerting upward pressure on food prices of basic cereals (Nelson *et al.*, 2009; Hertel *et al.*, 2010), which would have serious implications for Africa's food security. As the recent wave of food price crises demonstrates, factors in other regions profoundly impact food security in Africa. Much more research is needed to understand better the potential interactions between climate change and other key drivers of food prices that act at national, regional, and global scales. (See also Chapter 7.2.2.)

Africa is undergoing both rapid urbanization and subsequent transformation of its food systems to accommodate changes in food processing and marketing as well as in food consumption patterns. Considering the increasing reliance on purchased food in urban areas, approaches for addressing the impacts of climate change on food security will need to encompass a food systems approach (production as well as processing, transport, storage, and preparation) that moves food from production to consumption (Battersby, 2012). Weaknesses in the food system may be exacerbated by climate change in the region as high temperatures increase spoilage and the potential for increased flooding places food transportation infrastructure at higher risk of damage. In this respect, high post-harvest losses in Africa resulting in a large part from inadequate transport and storage infrastructure (Godfray *et al.*, 2010; Parfitt *et al.*, 2010) are an important concern.

22.3.5. Health

22.3.5.1. Introduction

Africa currently experiences high burdens of health outcomes whose incidence and geographic range could be affected by changing temperature and precipitation patterns, including malnutrition, diarrheal diseases, and malaria and other vector-borne diseases, with most of the impact on women and children (WHO 2013a). In 2010, there were 451,000 to 813,000 deaths from malaria in Africa, continuing a slow decline since approximately 2004 (WHO, 2012). There are insufficient data series to assess trends in incidence in most affected countries in Africa. Parasite prevalence rates in children less than 5 years of age are highest in poorer populations and rural areas; factors increasing vulnerability include living in housing with little mosquito protection and limited access to health care facilities offering effective diagnostic testing and treatment. Of the 3.6 million annual childhood deaths in Africa, 11% are due to diarrheal diseases (Liu *et al*., 2012).

Drivers of these and other climate-relevant health outcomes include inadequate human and financial resources, inadequate public health and health care systems, insufficient access to safe water and improved sanitation, food insecurity, and poor governance. Although progress has been made on improving safe water and sanitation coverage, sub-Saharan Africa still has the lowest coverage, highlighting high vulnerability to the health risks of climate change (UNICEF and WHO, 2008; UNICEF and WHO, 2012). Vulnerabilities also arise from policies and measures implemented in other sectors, including adaptation and mitigation options. Collaboration between sectors is essential. For example, the construction of the Akosombo dam in the 1960s to create Lake Volta in Ghana was associated with a subsequent increase in the prevalence of schistosomiasis (Scott *et al*., 1982).

22.3.5.2. Food- and Water-Borne Diseases

Cholera is primarily associated with poor sanitation, poor governance, and poverty, with associations with weather and climate variability suggesting possible changes in incidence and geographic range with climate change (Rodó *et al.*, 2002; Koelle *et al.*, 2005; Olago *et al.*, 2007; Murray *et al.*, 2012). The frequency and duration of cholera outbreaks are associated with heavy rainfall in Ghana, Senegal, other coastal West African countries, and South Africa, with a possible association with the El Niño-Southern Oscillation (ENSO) (de Magny *et al.*, 2007;

Mendelsohn and Dawson, 2008; de Magny *et al*., 2012). In Zanzibar, Tanzania, and Zambia, an increase in temperature or rainfall increases the number of cholera cases (Luque Fernández *et al*., 2009; Reyburn *et al*., 2011). The worst outbreak of cholera in recent African history occurred in Zimbabwe from August 2008 to June 2009. The epidemic was associated with the rainy season and caused more than 92,000 cases and 4,000 deaths. Contamination of water sources spread the disease (Mason, 2009). Poor governance, poor infrastructure, limited human resources, and underlying population susceptibility (high burden of malnutrition) contributed to the severity and extent of the outbreak (Murray *et al.*, 2012). Other mechanisms for increases in cholera incidence have been described in Chapter 11 (11.5.2.1). As discussed above in section 22.2 there are projected increases in precipitation in areas in Africa for example West Africa where cholera is already endemic. This possibly will lead to more frequent cholera outbreaks in the sub-regions affected. However, further research is needed to quantify the climatic impacts.

22.3.5.3. Nutrition

Malnutrition: Detailed spatial analyses of climate and health dynamics among children in Mali and Kenya suggest associations between livelihoods and measures of malnutrition, and between weather variables and stunting (Grace *et al*., 2012; Jankowska *et al*., 2012). Projections of climate and demographic change to 2025 for Mali (based on 2010-2039 climatology from the Famine Early Warning System Network FCLIM method), suggest approximately 250,000 children will suffer stunting, nearly 200,000 will be malnourished, and over 100,000 will become anemic, assuming constant morbidity levels; the authors conclude that climate change will cause a statistically significant proportion of stunted children (Jankowska *et al*., 2012).

Using a process-driven approach, (Lloyd *et al.*, 2011) projected future child malnutrition (as measured by severe stunting) in 2050 for four regions in sub-Saharan Africa, taking into consideration food and nonfood (socioeconomic) causes, and using regional scenario data based on the A2 scenario. Current baseline prevalence rates of severe stunting were 12-20%. Considering only future socioeconomic change, the prevalence of severe stunting in 2050 would be 7-17% (e.g. a net decline). However, including climate change, the prevalence of severe stunting would be 9-22%, or an increase of 31-55%in the relative percent of children severely stunted. Western sub-Saharan Africa was projected to experience a decline in severe stunting from 16% at present to 9% in 2050 when considering socioeconomic and climate change. Projected changes for central, south, and east sub-Saharan Africa are close to current prevalence rates, indicating climate change would counteract the beneficial consequences of socioeconomic development. Local economic activity and food accessibility can reduce the incidence of malnutrition (Funk *et al.*, 2008; Rowhani *et al.*, 2011).

22.3.5.4. Vector-Borne Diseases and Other Climate-Sensitive Health Outcomes

A wide range of vector-borne diseases contribute to premature morbidity and mortality in Africa, including malaria, leishmaniasis, Rift Valley fever, as well as tick- and rodent-borne diseases.

Malaria: Weather and climate are among the environmental, social, and economic determinants of the geographic range and incidence of malaria (Reiter 2008). The association between temperature and malaria varies regionally, (Chaves and Koenraadt, 2010; Paaijmans *et al.*, 2010a; Alonso *et al.*, 2011; Gilioli and Mariani, 2011). Malaria transmission peaks at 25°C and declines above 28°C (Lunde *et al.*, 2013; Mordecai *et al*., 2013). Total precipitation, rainfall patterns, temperature variability, and the water temperature of breeding sites are expected to alter disease susceptibility (Bomblies and Eltahir, 2010; Paaijmans *et al.*, 2010b; Afrane *et al.*, 2012; Blanford *et al.*, 2013; Lyons *et al.*, 2013). ENSO events also may contribute to malaria epidemics (Mabaso *et al.*, 2007; Ototo *et al.*, 2011). The complexity of the malaria transmission cycle makes it difficult to determine whether the distribution of the pathogen and vector are already changing due to climate change. Other factors like the Indian Ocean Dipole have been proposed to affect malaria incidence (Hashizume et al., 2009, Chaves et al., 2012, Hashizume et al., 2012).

Climate change is expected to affect the geographic range and incidence of malaria, particularly along the current edges of its distribution, with contractions and expansions, and increasing and decreasing incidence (Yé *et al.*, 2007; Peterson, 2009; Parham and Michael, 2010; Paaijmans *et al.*, 2010b; Alonso *et al.*, 2011; Egbendewe-Mondzozo *et* *al.*, 2011; Chaves *et al.*, 2012; Paaijmans *et al.*, 2012; Parham *et al.*, 2012; Ermert *et al.*, 2012), depending on other drivers, such as public health interventions, factors influencing the geographic range and reproductive potential of malaria vectors, land use change (e.g., deforestation), and drug resistance, as well as the interactions of these drivers with weather and climate patterns (Chaves *et al.*, 2008; Kelly-Hope *et al.*, 2009; Paaijmans *et al.*, 2009; Saugeon *et al.*, 2009; Artzy-Randrup *et al.*, 2010; Dondorp *et al.*, 2010; Gething *et al.*, 2010; Jackson *et al.*, 2010; Kulkarni *et al.*, 2010; Loha and Lindtjørn, 2010; Tonnang *et al.*, 2010; Stern *et al.*, 2011; Caminade *et al.*, 2011; Omumbo *et al.*, 2011; Afrane *et al.*, 2012; Edlund *et al.*, 2012; Githeko *et al.*, 2012; Himeidan and Kweka, 2012; Jima *et al.*, 2012; Lyons *et al.*, 2012; Ermert *et al.*, 2012; Stryker and Bomblies, 2012; Mordecai *et al.*, 2013). Movement of the parasite into new regions is associated with epidemics with high morbidity and mortality. Because various *Anopheles* species are adapted to different climatic conditions, changing weather and climate patterns could affect species composition differentially, which could, in turn affect malaria transmission (Afrane *et al.*, 2012; Lyons *et al.*, 2013).

Consensus is growing that highland areas, especially in East Africa, will experience increased malaria epidemics, with areas above 2,000 m, with temperatures currently too low to support malaria transmission, particularly affected (Pascual *et al.*, 2006; Peterson, 2009; Gething *et al.*, 2010; Lou and Zhao, 2010; Paaijmans *et al.*, 2010a; Ermert *et al.*, 2012). Reasons for different projections across models include use of different scenarios; use of global versus regional climate models (Ermert *et al.*, 2012); the need for finer-scale and higher-resolution models of the sharp climate variations with altitude (Bouma *et al.*, 2011); and the extent to malaria transmission and the drivers of its geographic range and incidence of malaria respond to and interact with climate change.

Leishmaniasis: Directly or indirectly, climate change may increase the incidence and geographic range of leishmaniasis, a highly neglected disease that has recently become a significant health problem in northern Africa (Postigo, 2010), with a rising concern in western Africa because of co-infection with HIV (Kimutai *et al.*, 2006). The epidemiology of the disease appears to be changing (Dondji, 2001; Yiougo *et al.*, 2007; WHO, 2009; Postigo, 2010). During the 20th century, zoonotic cutaneous leishmaniasis emerged as an epidemic disease in Algeria, Morocco, and Tunisia, and is now endemic (Salah *et al.*, 2007; Aoun *et al.*, 2008; Rhajaoui, 2011; Toumi *et al.*, 2012; Bounoua *et al.*, 2013). Previously an urban disease in Algeria, leishmaniasis now has a peri-urban distribution linked to changes in the distribution of the rodent host and of the vector since the early 1990s (Aoun *et al.*, 2008). Cutaneous leishmaniasis has expanded its range from its historical focus at Biskra, Algeria into the semi-arid steppe, with an associated upward trend in reported cases. In Morocco, sporadic cases of leishmania major (vector *Phlebotomus papatasi*) appeared early in the 20th century; since that time there have been occasional epidemics of up to 2,000 cases, interspersed with long periods with few or no cases (Rhajaoui, 2011). Outbreaks of zoonotic cutaneous leishmaniasis have become more frequent in Tunisia (where it emerged as an epidemic disease in 1991) (Salah *et al.*, 2007; Toumi *et al*., 2012). The disease has since spread to adjacent areas in West Africa and East Africa (Dondji, 2001; Yiougo *et al.*, 2007; WHO, 2009). Disease incidence is associated with rainfall and minimum temperature (Toumi *et al.*, 2012; Bounoua *et al.*, 2013). Relationships between decadal shifts over 1990-2009 in northwest Algeria and northeast Morocco in the number of cases and climate indicators suggested increased minimum temperatures created conditions suitable for endemicity (Bounoua *et al.*, 2013). Environmental modifications, such as construction of dams, can change the temperature and humidity of the soil and thus affect vegetation that may result in changes in the composition and density of sandfly species and rodent vectors. More research however, is needed to quantity the climate related impacts because there are multiple underlying factors.

Rift Vally fever (RVF): RVF epidemics in the Horn of Africa are associated with altered rainfall patterns. Additional climate variability and change could further increase its incidence and spread. Rift Valley fever is endemic in numerous African countries, with sporadic repeated epidemics. Epidemics in 2006–2007 in the Horn of Africa (Nguku *et al.*, 2007; WHO, 2007; Adam *et al.*, 2010; Andriamandimby *et al.*, 2010; Hightower *et al*., 2012) and southern Africa were associated with heavy rainfall (Chevalier *et al.*, 2011), strengthening earlier analyses by Anyamba *et al.* (2009) showing that RVF epizootics and epidemics are closely linked to the occurrence of the warm phase of ENSO and La Nina events (Linthicum *et al.*, 1999; Anyamba *et al.*, 2012) and elevated Indian Ocean temperatures. These conditions lead to heavy rainfall and flooding of habitats suitable for the production of the immature *Aedes* and *Culex* mosquitoes that serve as the primary RVF virus vectors in East Africa. Flooding of mosquito habitats also may introduce the virus into domestic animal populations.

Ticks and tick-borne diseases: Changing weather patterns could expand the distribution of ticks causing animal disease, particularly in East and South Africa. Ticks carry theileriosis (East Coast Fever), which causes anemia and skin damage that expose cattle to secondary infections. Habitat destruction, land use and cover change, and host density also affect tick distribution (Rogers and Randolph, 2006). Using a climate envelope and a species prediction model, Olwoch *et al*. (2007) projected that by 2020s, under the A2 scenario, East Africa and South Africa would be particularly vulnerable to climate-related changes in tick distributions and tick-borne diseases: more than 50% of the 30 *Rhipicephalus* species examined showed significant range expansion and shifts. More than 70% of this range expansion was found in tick species of economic importance.

Schistosomiasis: Worldwide, approximately 243 million people required treatment for schistosomiasis in 2011, of which 90% lived in underdeveloped areas of Africa (WHO, 2013b). Water resource development, such as irrigation dams recommended for adaptation in agriculture, can amplify the risk of schistosomiasis (Huang and Manderson, 1992; Hunter *et al.*, 1993; Jobin, 1999). Migration and sanitation play a significant role in the spread of schistosomiasis from rural areas to urban environments (Babiker *et al.*, 1985; WHO, 2013b). Temperature and precipitation patterns may play a role in transmission (Odongo-Aginya *et al.*, 2008; Mutuku *et al.*, 2011; Huang *et al*., 2011). Projections for the period 2070-2099, under A2 and B2 emission scenarios, suggest that although the geographic areas suitable for transmission will increase with climate change, snail regions are expected to contract and/or move to cooler areas; these results highlight the importance of understanding how climate change could alter snail habitats when projecting future human schistosomiasis prevelance under different scenarios (Stensgaard *et al*. 2011).

Meningococcal meningitis: There is a strong environmental relationship between the seasonal cycle of meningococcal meningitis and climate, including a relationship between the seasonal pattern of the Harmattan dusty winds and onset of disease. Transmission of meningitis occurs throughout Africa in the dry season and coincides with periods of very low humidity and wind-driven dusty conditions, ending with the onset of the rains (Molesworth *et al.*, 2003). Research corroborates earlier hypothesized relationships between weather and meningitis (Yaka *et al.*, 2008; Palmgren, 2009; Roberts, 2010; Dukić *et al.*, 2012; Agier *et al*., 2013). In the northern region of Ghana, exposure to smoke from cooking fires increased the risk of contracting meningococcal meningitis (Hodgson *et al*., 2001). This increased risk suggests that exposure to elevated concentrations of air pollutants, such as carbon monoxide (CO) and particulate matter, may be linked to illness. More research is needed to clarify the possible impact of climate change on atmospheric concentrations of aerosols and particulates that can impact human health and any associations between meningitis and these aerosols and particles. The relationship between the environment and the location of the epidemics suggest connections between epidemics and regional climate variability (Molesworth *et al.*, 2003; Sultan *et al.*, 2005; Thomson *et al.*, 2006) which may allow for early warning systems for predicting the location and onset of epidemics.

Hantavirus: Novel hantaviruses with unknown pathogenic potential have been identified in some insectivores (shrews and a mole) in Africa (Klempa, 2009), with suggestions that weather and climate, among other drivers, could affect natural reservoirs and their geographic range, and thus alter species composition in ways that could be epidemiologically important (Klempa, 2009).

Other health issues: Research into other health issues has begun. It has been noted that any increase in food insecurity due to climate change would be expected to further compromise the poor nutrition of people living with HIV/AIDs (Drimie and Gillespie, 2010). Laboratory studies suggest that the geographic range of the tsetse fly (*Glossina* species), the vector of human and animal trypanosomiasis in Africa, may be reduced with climate change (Terblanche *et al.*, 2008). More studies are needed to clarify the role of climate change on HIV and other disease vectors.

Heat waves and high ambient temperatures: Heat waves and heat-related health effects are only beginning to attract attention in Africa. High ambient temperatures are associated with increased mortality in Ghana, Burkina Faso, and Nairobi with associations varying by age, gender, and cause of death (Azongo *et al*., 2012; Diboulo *et al*., 2012; Egondi *et al*., 2012). Children are particularly at risk. Heat-related health effects also may be of concern in West and southern Africa (Dapi *et al.*, 2010; Mathee *et al.*, 2010). Chapter 11 (11.4.1) assesses the literature on the health impacts of heat waves and high ambient temperatures. Low ambient temperatures are associated with mortality in

Nairobi and Tanzania (Egondi *et al*., 2012; Mrema *et al*., 2012). Chapter 11 discusses the relationship between heat and work capacity loss. This is an important issue for Africa because of the number of workers engaged in agriculture.

Air quality: Climate change is anticipated to affect the sources of air pollutants as well as the ability of pollutants to be dispersed in the atmosphere (Denman *et al.*, 2007). Assessments of the impacts of projected climate change on atmospheric concentrations of aerosols and particules that can adversely affect human health indicate that changes in surface temperature, land cover, and lightning may alter natural sources of ozone precursor gases and consequently ozone levels over Africa (Stevenson *et al.*, 2005; Brasseur *et al.*, 2006; Zeng *et al.*, 2008). However, insufficient climate and emissions data for Africa prevent a more comprehensive assessment and further research is needed to better understand the implications of climate change on air quality in Africa.

22.3.6. Urbanization

The urban population in Africa is projected to triple by2050, increasing by 0.8 billion (UN DESA, 2010). African countries are experiencing some of the world's highest urbanization rates (UN-Habitat, 2008). Many of Africa's evolving cities are unplanned and have been associated with growth of informal settlements, inadequate housing and basic services, and urban poverty (Yuen and Kumssa, 2011).[7]

[FOOTNOTE 7: However, community-driven upgrading may contribute to reducing the vulnerability of such informal areas (for more details see Chapter 8).]

Climate change could affect the size and characteristics of rural and urban human settlements in Africa because the scale and type of rural-urban migration are partially driven by climate change (UN-Habitat and UNEP, 2010; Yuen and Kumssa, 2011). The majority of migration flows observed in response to environmental change are within country boundaries (Jäger *et al.*, 2009; Tacoli, 2009). For large urban centers located on mega-deltas (e.g., Alexandria in Egypt in the Nile delta, and Benin City, Port Harcourt, and Aba in Nigeria in the Niger delta), urbanization through migration may also lead to increasing numbers of people vulnerable to coastal climate change impacts (Seto, 2011). Floods are exerting considerable impacts on cities and smaller urban centers in many African nations – for example, heavy rains in East Africa in 2002 caused floods and mudslides, which forced tens of thousands to leave their homes in Rwanda, Kenya, Burundi, Tanzania and Uganda, and the very serious floods in Port Harcourt and Addis Ababa in 2006 (Douglas *et al.*, 2008).

Additionally sea level rise along coastal zones including coastal settlements could disrupt economic activities such as tourism and fisheries (Naidu *et al*., 2006; Kebede *et al.*, 2012, Kebede and Nicholls, 2012). More than a quarter of Africa's population lives within 100 km of the coast and more than half of Africa's total population living in low-elevation coastal zones is urban, accounting for 11.5% of the total urban population of the continent (UN-Habitat, 2008).

In eastern Africa, an assessment of the impact of coastal flooding due to sea level rise in Kenya found that, by 2030, 10,000 to 86,000 people would be affected, with associated economic costs ranging between US$ 7 million to US$ 58 million (SEI, 2009). Detailed assessments of damages arising from extreme events have also been made for some coastal cities, including Mombasa and Dar-es-Salaam. In Mombasa, by 2030 the population and assets at risk of 1 in 100-year return period extreme water levels is estimated to be between 170,700 to 266,300 inhabitants, while economic assets at risk are between US$ 0.68 billion and 1.06 billion (Kebede *et al.*, 2012). In Dar-es-Salaam, the population and economic assets at risk of 1 in 100-year return period extreme water levels by 2030 range between 30,300 and 110,000 inhabitants and US$ 35.6 million to US$ 404.1 million (Kebede and Nicholls, 2012). For both city assessments, the breadth of these ranges encompasses three different population growth scenarios and four different sea-level rise scenarios (low (B1), medium (A1B), high (A1FI), and Rahmstorf (based on Rahmstorf, 2007)); these four sea-level rise scenarios were also the basis for the broader assessment of the coast of Kenya (SEI, 2009). The scale of the damages projected in the city-specific studies highlights the risks of extremes in the context of projected sea-level rise.

In southern Africa, urban climate change risk assessments have been made at the regional scale (Theron and Rossouw, 2008) as well as at the city level for Durban, Cape Town, and the uMhlathuze local municipality. For these cities, risk assessments have focused on a broad range of sectors, including business and tourism; air quality, heath, and food security; infrastructure and services; biodiversity; and water resources (Naidu *et al.*, 2006; Cartwright, 2008; Zitholele Consulting, 2009).

Assessments for western Africa (Appeaning Addo *et al.*, 2008; Niang *et al.*, 2010) and northern Africa (Snoussi *et al.*, 2009; World Bank, 2011) share similarities with those for eastern and southern Africa. For instance, it was suggested that by the end of the 21st century, about 23 %, 42 %, and 49 % of the total area of coastal governorates of the Nile Delta would be susceptible to inundation under the A1FI, Rahmstorf and Pfeffer scenarios of SLR. It was also suggested that a considerable proportion of these areas (ranging between 32% and 54 %) are currently either wetland or undeveloped areas (Hassaan and Abdrabo, 2013). Another study, assessing the economic impacts of sea level rise on the Nile Delta, suggested that losses in terms of housing and road would range between 1 and 2 billion EGP in 2030 and between 2 and 16 billion EGP in 2060 under the A1FI and B1 emissions scenarios as well as current sea level rise trends (Smith *et al.*, 2013).

African cities and towns represent highly vulnerable locations to the impacts of climate change and climate variability (Boko *et al.*, 2007; Diagne, 2007; Dossou and Gléhouenou-Dossou, 2007; Douglas *et al.*, 2008; Adelekan, 2010; Kithiia, 2011). Rapid rates of urbanization represent a burden on the economies of African urban areas, due to the massive investments needed to create job opportunities and provide infrastructure and services. Basic infrastructure services are not keeping up with urban growth, which has resulted in a decline in the coverage of many services, compared to 1990 levels (Banerjee *et al.*, 2007). Squatter and poor areas typically lack provisions to reduce flood risks or to manage floods when they happen (Douglas *et al.*, 2008).

African small- and medium-sized cities have limited adaptive capacity to deal not only with future climate impacts but also with the current range of climate variability (Satterthwaite *et al*., 2009; UN-Habitat, 2011); for more details see Chapter 5 and Chapter 8). African cities, despite frequently having more services compared to rural areas (e.g., piped water, sanitation, schools and healthcare) that lead to human life spans above their respective national averages, show a shortfall in infrastructure due to low quality and short lifespan which may be of particular concern, when climate change impacts are taken into consideration (Satterthwaite *et al*., 2009). It is not possible, however, "to climate-proof infrastructure that is not there" (Satterthwaite *et al.*, 2009). At the same time, hard infrastructural responses such as seawalls and channelized drainage lines are costly and can be maladaptive (Dossou and Gléhouenou-Dossou, 2007; Douglas *et al.*, 2008; Kithiia and Lyth, 2011).

High levels of vulnerability and low adaptive capacity results from structural factors, particularly local governments with poor capacities and resources (Kithiia, 2011). Weak local government creates and exacerbates problems including the lack of appropriate regulatory structures and mandates; poor or no planning; lack of or poor data; lack of disaster risk reduction strategies; poor servicing and infrastructure (particularly waste management and drainage); uncontrolled settlement of high-risk areas such as floodplains, wetlands, and coastlines; ecosystem degradation competing development priorities and timelines; and a lack of coordination among government agencies (AMCEN and UNEP, 2006; Diagne, 2007; Dossou and Gléhouenou-Dossou, 2007; Mukheibir and Ziervogel, 2007; Douglas *et al.*, 2008; Roberts, 2008; Adelekan, 2010; Kithiia and Dowling, 2010; Kithiia, 2011).

22.4. Adaptation

22.4.1. Introduction

Since 2007, Africa has gained experience in conceptualizing, planning and beginning to implement and support adaptation activities, from local to national levels and across a growing range of sectors (22.4.4, 22.4.5). However, across the continent, most of the adaptation to climate variability and change is reactive in response to short-term motivations, is occurring autonomously at the individual / household level, and lacks support from government stakeholders and policies (Vermuelen *et al.*, 2008; Ziervogel *et al.*, 2008; Berrang-Ford *et al.*, 2011). A complex web of interacting barriers to local-level adaptation, manifesting from national to local scales, both constrains and highlights potential limits to adaptation (22.4.6).

22.4.2. Adaptation Needs, Gaps, and Adaptive Capacity

Africa's urgent adaptation needs stem from the continent's foremost sensitivity and vulnerability to climate change, together with its low levels of adaptive capacity (Ludi *et al.*, 2012; 22.3). While overall adaptive capacity is considered low in Africa due to economic, demographic, health, education, infrastructure, governance and natural factors, levels vary within countries and across sub-regions, with some indication of higher adaptive capacity in North Africa and some other countries; individual or household level adaptive capacity depends, in addition to functional institutions and access to assets, on the ability of people to make informed decisions to respond to climatic and other changes (Vincent, 2007; Ludi *et al.*, 2012).

Inherent adaptation-related strengths in Africa include the continent's wealth in natural resources, well-developed social networks, and longstanding traditional mechanisms of managing variability through, for example, crop and livelihood diversification, migration and small-scale enterprises, all of which are underpinned by local or indigenous knowledge systems for sustainable resource management (Eyong, 2007; Nyong *et al.*, 2007; UNFCCC, 2007; Cooper *et al.*, 2008; Macchi *et al.*, 2008; Nielsen, 2010; Castro *et al.*, 2012;). However, it is uncertain to what extent these strategies will be capable of dealing with future changes, among them climate change and its interaction with other development processes (Leary *et al.*, 2008b; Paavola, 2008; van Aalst *et al.*, 2008; Conway, 2009; Jones, 2012, section 22.4.6). Since Africa is extensively exposed to a range of multiple stressors (22.3) that interact in complex ways ith longer term climate change, adaptation needs are broad, encompassing institutional, social, physical and infrastructure needs, ecosystem services and environmental needs, and financial and capacity needs.

Making climate change information more reliable and accessible is one of the most pressing and cross-cutting adaptation needs, but providing information is insufficient to guarantee adaptation, which requires behavioural change (22.4.5.5, 22.4.6). As noted in the AR4 and emphasised in subsequent literature, monitoring networks in Africa are insufficient and characterised by sparse coverage and short and fragmented digitised records, which makes modelling difficult (Boko *et al.*, 2007; Goulden *et al.*, 2009b; Ziervogel and Zermoglio, 2009; Jalloh *et al.*, 2011a). Adding to this is the shortage of relevant information and skills, in particular for downscaling climate models and using scenario outputs for development and adaptation planning, which is exacerbated by under-resourcing of Meteorological Agencies and a lack of in-country expertise on climate science; and the capacity of civil society and government organisations' to access, interpret and use climate information for planning and decisionmaking (Ziervogel and Zermoglio, 2009; Brown *et al.*, 2010; Ndegwa *et al.*, 2010; Dinku *et al.*, 2011; Jalloh *et al.*, 2011a).

Given its economic dependence on natural resources, most research on strengthening adaptive capacity in Africa is focused on agriculture, forestry or fisheries-based livelihoods (Collier *et al.*, 2008; Berrang-Ford *et al.*, 2011). The rural emphasis is now being expanded through a growing focus on requirements for enhancing peri-urban and urban adaptive capacity (Lwasa, 2010; Ricci, 2012). Many African countries have prioritised the following knowledge needs: vulnerability and impact assessments with greater continuity in countries; country-specific socio-economic scenarios and greater knowledge on costs and benefits of different adaptation measures; comprehensive programmes that promote adaptation through a more holistic development approach, including integrated programmes on desertification, water management and irrigation; promoting sustainable agricultural practices and the use of appropriate technologies and innovations to address shorter growing seasons, extreme temperatures, droughts, and floods; developing alternative sources of energy; and approaches to deal with water shortages, food security and loss of livelihoods (UNFCCC, 2007; Bryan *et al.*, 2009; Eriksen and Silva, 2009; Chikozho, 2010; Gbetibouo *et al.*, 2010b; Jalloh *et al.*, 2011b; Sissoko *et al.*, 2011; AAP, 2012). The literature, however, stresses the vast variety of contexts that shape adaptation and adaptive capacity - even when people are faced with the same climatic changes and livelihood stressors, responses vary greatly (Cooper *et al.*, 2008; Vermuelen *et al.*, 2008; Ziervogel *et al.*, 2008; Gbetibouo, 2009; Westerhoff & Smit, 2009)

Despite significant data and vulnerability assessment gaps, the literature highlights that delayed action on adaptation due to this would not be in the best interests of building resilience commensurate with the urgent needs (UNFCCC, 2007; Jobbins, 2011). See section 22.6.4 for a discussion of adaptation costs and climate finance.

22.4.3. Adaptation, Equity, and Sustainable Development

Multiple uncertainties in the African context mean that successful adaptation will depend upon developing resilience in the face of uncertainty (*high confidence)* (Adger *et al.,* 2011; Conway, 2011; Ludi *et al.,* 2012). The limited ability of developmental strategies to counter current climate risks, in some cases due to significant implementation challenges related to complex cultural, political and insitutional factors, has led to an adaptation deficit, which reinforces the desirability for strong inter-linkages between adaptation and development, and for low-regrets adaptation strategies (see AR5 Glossary) that produce developmental co-benefits (*high confidence*) (Bauer and Scholz, 2010; Smith *et al.*, 2011).

Research has highlighted that no single adaptation strategy exists to meet the needs of all communities and contexts in Africa (*high confidence*) (22.4.4, 22.4.5). In recognition of the socioeconomic dimensions of vulnerability (Bauer and Scholz, 2010), the previous focus on technological solutions to directly address specific impacts is now evolving toward a broader view that highlights the importance of building resilience, through social, institutional, policy, knowledge, and informational approaches (ADF, 2010; Chambwera and Anderson, 2011), as well as on linking the diverse range of adaptation options to the multiple livelihood–vulnerability risks faced by many people in Africa (Tschakert and Dietrich, 2010), and on taking into account local norms and practices in adaptation strategies (Nyong *et al*., 2007; Ifejika Speranza *et al*., 2010; section 22.4.5.4). Moreover, effective adaptation responses necessitate differentiated and targeted actions from the local to national levels, given the differentiated social impacts based on gender, age, disability, ethnicity, geographical location, livelihood, and migrant status (Tanner and Mitchell, 2008; IPCC, 2012). Additional attention to equity and social justice aspects in adaptation efforts in Africa, including the differential distribution of adaptation benefits and costs, would serve to enhance adaptive capacity (Burton *et al.*, 2002; Brooks *et al.,* 2005; Thomas and Twyman, 2005; Madzwamuse, 2010); nevertheless, some valuable experience has been gained recently on gender-equitable adaptation, human rights based-approaches, and involvement of vulnerable or marginalized groups such as indigenous peoples and children, aged and disabled people, internally displaced persons and refugees (ADF, 2010; UNICEF, 2010; Levine *et al.*, 2011; UNICEF, 2011; Romero González *et al*., 2011; IDS, 2012; Tanner and Seballos, 2012) (Table 22-5). See also CC-GC on Gender and Climate Change.

[INSERT TABLE 22-5 HERE
Table 22-5: Cross-cutting approaches for equity and social justice in adaptation.]

22.4.4. Experiences in Building the Governance System for Adaptation, and Lessons Learned

22.4.4.1. Introduction

Section 22.4.4 assesses progress made in developing policy, planning and institutional systems for climate adaptation at regional, national and sub-national levels in Africa, with some assessment of implementation. This includes an assessment of community-based adaptation, as an important local level response, and a consideration of adaptation decisionmaking and monitoring.

22.4.4.2. Regional and National Adaptation Planning and Implementation

Regional policies and strategies for adaptation, as well as transboundary adaptation, are still in their infancy. Early examples include the Climate Change Strategies and Action Plans being developed by the Southern African Development Community and the Lake Victoria Basin Committee, as well as efforts being made by six highly forested Congo basin countries to co-ordinate conservation and sustainable forest management of the Central African forest ecosystem, and obtain payments for ecosystem services (Harmeling *et al.*, 2011; AfDB, 2012).

At the national level, African countries have initiated comprehensive planning processes for adaptation by developing National Adaptation Programmes of Action (NAPAs), in the case of the Least Developed Countries, or National Climate Change Response Strategies (NCCRS); implementation is, however, lagging and integration with economic and development planning is limited but growing (*high confidence*). Prioritized adaptation measures in the NAPAs tend to focus narrowly on agriculture, food security, water resources, forestry, and disaster management; and onprojects, technical solutions, education and capacity development, with little integration with economic planning and poverty reduction processes (Madzwamuse, 2010; Mamouda, 2011; Pramova *et al.*, 2012). Only a small percentage of the NAPA activities have been funded to date, although additional funding is in the pipeline (Prowse *et al.*, 2009; Madzwamuse, 2010; Mamouda, 2011; Romero González *et al.*, 2011).

Subsequent to the NAPAs and early experience with the NCCRS, there is some evidence of evolution to a more integrated, multi-level and multi-sector approach to adaptation planning (*medium confidence*). Examples include Ethiopia's Programme of Adaptation to Climate Change, which includes sectoral, regional, national and local community levels (Hunde, 2012); Lesotho's co-ordinated policy framework involving all ministries and stakeholders (Corsi *et al.*, 2012); and Mali's experience with a methodology for integrating adaptation into multiple sectors (Fröde *et al.*, 2013). Cross-sectoral adaptation planning and risk management is occurring through mainstreaming initiatives like the twenty country Africa Adaptation Programme (AAP), initiated in 2008 (UNDP, 2009; Siegel, 2011). Examples of the more programmatic approach of national climate resilient development strategies include Rwanda's National Strategy on Climate Change and Low Carbon Development, under development in 2012, and the Pilot Programmes for Climate Resilience in Niger, Zambia and Mozambique (Climate Investment Fund, 2009). Inter-sectoral climate risk management approaches can be detected in integrated water resources management, integrated coastal zone management, disaster risk reduction, and land use planning initiatives (Boateng, 2006; Koch *et al*., 2007; Awuor *et al.*, 2008; Cartwright *et al.*, 2008; Kebede and Nicholls, 2011; Kebede *et al.*, 2012), while in South Africa, climate change design principles have been incorporated into existing systematic biodiversity planning to guide land use planning (Petersen and Holness, 2011).

The move to a more integrated approach to adaptation planning is occurring within efforts to construct enabling national policy environments for adaptation in many countries. Examples include Namibia's National Policy on Climate Change; Zambia's National Climate Change Response Strategy and Policy, and South Africa's National Climate Change Response Policy White Paper. Ten countries were developing new climate change laws or formal policies at the end of 2012, including the proposed National Coastal Adaptation Law in Gabon (Corsi *et al.*, 2012).

Despite this progress in mainstreaming climate risk in policy and planning, significant disconnects still exist at the national level, and implementation of a more integrated adaptation response remains tentative (*high confidence*) (Koch *et al.*, 2007; Fankhauser and Schmidt-Traub, 2010; Madzwamuse, 2010; Oates *et al*., 2011; UNDP-UNEP Poverty-Environment Initiative, 2011a). Legislative and policy frameworks for adaptation remain fragmented, adaptation policy approaches seldom take into account realities in the political and institutional spheres, and national policies are often at odds with autonomous local adaptation strategies, which can act as a barrier to adaptation, especially where cultural, traditional and context-specific factors are ignored (Dube and Sekhwela, 2008; Patt and Schröter, 2008; Stringer *et al.*, 2009; Bele *et al.* 2010; Hisali *et al.*, 2011; Kalame *et al.* 2011; Naess *et al.*, 2011; Lockwood, 2012; Sonwa *et al.* 2012; section 22.4.6). While climate resilience is starting to be mainstreamed into economic planning documents - for example, Zambia's Sixth National Development Plan 2011-2015, and the new Economic and Social Investment Plan in Niger (Corsi *et al.*, 2012), measures to promote foreign direct investment and industrial competitiveness can undercut adaptive capacity of poor people (Madzwamuse, 2010), while poor business environments impede both foreign direct investment and adaptation (Collier *et al*., 2008). Stakeholders in climate-sensitive sectors – for example, Botswana's tourism industry - have yet to develop and implement adaptation strategies (Saarinen *et al*., 2012).

22.4.4.3. Institutional Frameworks for Adaptation

Global adaptation institutions, both within and outside of the UNFCCC, are critically important for Africa's ability to move forward on adaptation (14.2.3). Regional institutions focused on specific ecosystems rather than on political groupings, such as the Commission of Central African Forests (COMIFAC), present an opportunity to strengthen the institutional framework for adaptation. National frameworks include a number of institutions that cover all aspects of climate change: most countries have inter-ministerial coordinating bodies and inter-sectoral technical working groups, while an increasing number now have multi-stakeholder co-ordinating bodies (Harmeling et al, 2011) and are establishing national institutions to serve as conduits for climate finance (Gomez-Echeverri, 2010; Smith *et al.*, 2011).

Many studies in Africa show that under uncertain climatic futures, replacing hierarchical governance systems that operate within siloes with more adaptive, integrated, multi-level and flexible governance approaches, and with inclusive decisionmaking that can operate successfully across multiple scales – or adaptive governance and co-management – will enhance adaptive capacity and the effectivess of the adaptation response (Folke *et al.*, 2005; Olsson *et al.*, 2006; Koch *et al.*, 2007; Berkes, 2009; Pahl-Wostl, 2009; Armitage and Plummer, 2010; Bunce *et al.*, 2010a; Plummer, 2012). Despite some progress with developing the institutional framework for governing adaptation, there are significant problems with both transversal and vertical coordination, including institutional duplication with other inter-sectoral platforms, such for disaster risk reduction; while in fragile states, institutions for reducing climate risk and promoting adaptation may be extremely weak or almost non-existent (Hartmann and Sugulle, 2009; Sietz *et al.*, 2011; Simane *et al.*, 2012). Facilitating institutional linkages and co-ordinating responses across all boundaries of government, private sector and civil society would enhance adaptive capacity (Brown *et al.*, 2010). Resolving well-documented institutional challenges of natural resource management, including lack of co-ordination, monitoring and enforcement, is a fundamental step towards more effective climate governance. For example, concerning groundwater, developing organizational frameworks and strengthening institutional capacities for more effectively assessing and managing groundwater resources over the long term are critically important (Nyenje and Batelaan, 2009; Braune and Xu, 2010).

22.4.4.4. Sub-National Adaptation Governance

Since AR4, there has been additional effort on sub-national adaptation planning in African countries, but adaptation strategies at provincial and municipal levels are mostly still under development, with many local governments lacking the capacity and resources for the necessary decentralised adaptation response (*high confidence*). Provinces in some countries have developed policies and strategies on climate change: for example, Lagos State's 2012 Adaptation Strategy in Nigeria (BNRCC, 2012); mainstreaming adaptation into district development plans in Ghana; and communal climate resilience plans in Morocco (Corsi *et al.*, 2012). Promising approaches include sub-national strategies that integrate adaptation and mitigation for low-carbon climate resilient development, as is being done in Delta State in Nigeria, and in other countries (UNDP, 2011a). In response to the identified institutional weaknesses, capacity development has been implemented in many cities and towns, including initiatives in Lagos, Nigeria, Durban and Cape Town in South Africa: notable examples include Maputo's specialized local government unit to implement climate change response, ecosystem-based adaptation and improved city wetlands; and participatory skills development in integrating community-based disaster risk reduction and climate adaptation into local development planning in Ethiopia (Madzwamuse, 2010; ACCRA, 2012; Castán Broto, *et al.*, 2013).

22.4.4.5. Community-Based Adaptation and Local Institutions

Since AR4, there has been progress in Africa in implementing and researching community-based adaptation (*high confidence*), with broad agreement that support to local-level adaptation is best achieved by starting with existing local adaptive capacity, and incorporating and building upon present coping strategies and norms, including indigenous practices (Dube and Sekhwela, 2007; Archer *et al.*, 2008; Huq, 2011). Community-based adaptation (CBA) is community initiated, and/or draws upon community knowledge or resources – refer to AR5 glossary. Some relevant initiatives include the Community-based Adaptation in Africa (CBAA) project, which implemented community-level pilot projects in eight African countries (Sudan, Tanzania, Uganda, Zambia, Malawi, Kenya, Zimbabwe, South Africa) through a learning-by-doing approach; the Adaptation Learning Program, implemented in Ghana, Niger, Kenya and Mozambique (CARE International, 2012); and UNESCO Biosphere Reserves where good practices were developed in Ethiopia, Kenya, South Africa and Senegal (German Commission for UNESCO, 2011). See also section 22.4.5.6 on institutions for CBA. The literature includes a wide range of case studies detailing involvement of local communities in adaptation initiatives and projects facilitated by NGOs and researchers (for example, Leary *et al*., 2008a; CCAA, 2011; CARE International, 2012; Chishakwe *et al.,* 2012); these and other initiatives have generated process-related lessons (22.4.5), with positive assessments of effectiveness in improving adaptive capacity of African communities, local organisations and researchers (Lafontaine *et al*., 2012).

The key role for local institutions in enabling community resilience to climate change has been recognised, particularly with respect to natural resource dependent communities – for example, the role of NGOs and CBOs in catalysing agricultural adaptation or in building resilience through enhanced forest governance and sustainable management of non-timber forest products; institutions managing access to and tenure of land and other natural resources, which are vital assets for the rural and peri-urban poor, are particularly crucial for enabling CBA and enhancing adaptive capacity in Africa (Bryan *et al*., 2009; Brown *et al*., 2010; Mogoi *et al.*, 2010). Local studies and adaptation planning have revealed the following priorities for pro-poor adaptation: social protection, social services and safety nets; better water and land governance; action research to improve resilience of under-researched food crops of poor people; enhanced water storage and harvesting; better post-harvest services; strengthened civil society and greater involvement in planning; and more attention to urban and peri-urban areas heavily affected by migration of poor people (Moser and Satterthwaite, 2008; Urquhart, 2009; Bizikova *et al*., 2010).

22.4.4.6. Adaptation Decisionmaking and Monitoring

Emerging patterns in Africa regarding adaptation decision-making, a critical component of adaptive capacity, include limited inclusive governance at the national level, with greater involvement in local initiatives of vulnerable and exposed people in assessing and choosing adaptation responses (*high confidence*). Civil society institutions and communities have to date played a limited role in formulation of national adaptation policies and strategies, highlighting the need for governments to widen the political space for citizens and institutions to participate in decision-making, for both effectiveness and to ensure rights are met (Madzwamuse, 2010; Castro *et al*., 2012). Building African leadership for climate change may assist with this (CCAA, 2011; Chandani, 2011; Corsi *et al.*, 2012). A critical issue is how planning and decisionmaking for adaptation uses scientific evidence and projections, while also managing the uncertainties within the projections (Conway, 2011; Dodman and Carmin, 2011).

A range of tools has been used in adaptation planning in Africa, including vulnerability assessment (22.4.5), risk assessment, cost-benefit analysis, cost-effectiveness, multi-criteria analysis, and participatory scenario planning (see for example Cartwright *et al*., 2008; Kemp-Benedict and Agyemang-Bonsu, 2008; Njie *et al*., 2008; Mather and Stretch, 2012), but further development and uptake of decision tools would facilitate enhanced decisionmaking. A related point is that monitoring and assessing adaptation is still relatively undeveloped in Africa, with national co-ordinating systems for collating data and synthesizing lessons not in place. Approaches for assessing adaptation action at local and regional levels have been developed (see for example Hahn *et al.*, 2009; Gbetibouo *et al.*, 2010a; Below *et al*., 2012), while there are positive examples of local monitoring of adaptation at the project level (see for example Archer *et al.*, 2008; Below *et al*., 2012). Chapter 2 contains additional discussion of the foundations for decisionmaking on climate change matters.

22.4.5. Experiences with Adaptation Measures in Africa and Lessons Learned

22.4.5.1. Overview

Section 22.4.5 provides a cross-cutting assessment of experience gained in Africa with a range of adaptation approaches, encompassing climate risk reduction measures; processes for participatory learning and knowledge development and sharing; communication, education and training; ecosystem-based measures; and technological and infrastructural approaches; concluding with a discussion of maladaptation.

Common priority sectors across countries for implementing adaptation measures since 2008 include agriculture, food security, forestry, energy, water, and education (Corsi *et al.*, 2012), which reflects a broadening of focus since the AR4. While there has been little planning focus on regional adaptation (22.4.4.2, 22.4.4.3), the potential for this has been recognized (UNFCCC, 2007; Sonwa *et al.*, 2009; Niang, 2012).

Attention is increasing on identifying opportunities inherent in the continent's adaptation needs, as well as delineating key success factors for adaptation. A number of studies identify the opportunity inherent in implementing relatively low-cost and simple low-regrets adaptation measures that reduce people's vulnerability to current climate variability, have multiple developmental benefits, and are well-positioned to reduce vulnerability to longer-term climate change as well (UNFCCC, 2007; Conway and Schipper, 2011; see also Section 22.4.3). Responding to climate change provides an opportunity to enhance awareness that maintaining ecosystem functioning underpins human survival and development in a most fundamental way (Shackleton and Shackleton, 2012), and to motivate for new development trajectories (22.4.6). While it is difficult to assess adaptation success, given temporal and spatial scale issues, and local specificities, Osbahr *et al.* (2010) highlight the role of social networks and institutions, social resilience, and innovation as possible key success factors for adaptation in small-scale farming livelihoods in southern Africa. Kalame *et al.* (2008) note opportunities for enhancing adaptation through forest governance reforms to improve community access to forest resources, while Martens *et al.* (2009) emphasise the importance of 'soft path' measures for adaptation strategies (see also section 22.4.5.6).

The following discussion of adaptation approaches under discrete headings does not imply that these are mutually exclusive – adaptation initiatives usually employ a range of approaches simultaneously, and indeed, the literature increasingly recognizes the importance of this for building resilience.

22.4.5.2. Climate Risk Reduction, Risk Transfer, and Livelihood Diversification

Risk reduction strategies used in African countries to offset the impacts of natural hazards on individual households, communities, and the wider economy include early warning systems, emerging risk transfer schemes, social safety nets, disaster risk contingency funds and budgeting, livelihood diversification, and migration (World Bank, 2010; UNISDR, 2011).

Disaster risk reduction (DRR) platforms are being built at national and local levels, with the synergies between DRR and adaptation to climate change being increasingly recognized in Africa (Westgate, 2010; UNISDR, 2011; Hunde, 2012); however, Conway and Schipper (2011) find that additional effort is needed for a longer-term vulnerability reduction perspective in disaster management institutions.

Early warning systems (EWS) are gaining prominence as multiple stakeholders strengthen capabilities to assess and monitor risks and warn communities of a potential crisis, through regional systems such as the Permanent Inter-States Committee for Drought Control in the Sahel (CILSS) and the Famine Early Warning System Network (FEWS-NET), as well as national, local and community-based EWS on for example food and agriculture (Pantuliano and Wekesa, 2008; Sissoko *et al.*, 2011; FAO, 2011). Some of the recent EWS emphasise a gendered approach, and may incorporate local knowledge systems used for making short-, medium-, and long-term decisions about farming and livestock-keeping, as in Kenya (UNDP, 2011b). The health sector has employed EWS used to predict disease for adaptation planning and implementation, such as the prediction of conditions expected to lead to an outbreak of Rift Valley fever in the Horn of Africa in 2006/2007 (Anyamba *et al.*, 2010). Progress has been made in prediction of meningitis and in linking climate/weather variability and extremes to the disease (Thomson *et al.*, 2006; Cuevas *et al.*, 2007).

Local projects often use participatory vulnerability assessment or screening to design adaptation strategies (van Vliet, 2010; GEF Evaluation Office, 2011; Hambira, 2011), but vulnerability assessment at the local government level is often lacking, and assessments to develop national adaptation plans and strategies have not always been conducted in a participatory fashion (Madzwamuse, 2010). Kienberger (2012) details spatial modelling of social and economic vulnerability to floods at the district level in Búzi, Mozambique. Lessons from vulnerability analysis highlight that the highest exposure and risk do not always correlate with vulnerable ecosystems, socially marginalized groups, and areas with at-risk infrastructure, but may also lie in unexpected segments of the population (Moench, 2011).

Community-level DRR initiatives include activities that link food security, household resilience, environmental conservation, asset creation, and infrastructure development objectives and co-benefits (Parry *et al.*, 2009a; UNISDR, 2011; Frankenberger *et al.*, 2012). Food security and nutrition-related safety nets and social protection mechanisms can mutually reinforce each other for DRR that promotes adaptation, as in Uganda's Karamoja Productive Assets Programme (Government of Uganda and WFP 2010; WFP, 2011). Initiatives in Kenya, South Africa, Swaziland and Tanzania have also sought to deploy local and traditional knowledge for the purposes of disaster preparedness and risk management (Mwaura, 2008; Galloway McLean, 2010). Haan *et al.* (2012) highlight the need for increased donor commitment to the resilience-building agenda within the framework of DRR, based on lessons from the 2011 famine in Somalia.

Social protection[8], a key element of the African Union social policy framework, is being increasingly used in Ethiopia, Rwanda, Malawi, Mozambique, South Africa, and other countries to buffer against shocks by building assets and increasing resilience of chronically and transiently poor households; in some cases this surpasses repeated relief interventions to address slower onset climate shocks, as in Ethiopia's Productive Safety Net Program (Brown *et al.*, 2007; Heltberg *et al.* 2009). While social protection is helping with *ex post* and *ex ante* DRR and will be increasingly important for securing livelihoods should climate variability increase, less evidence exists for its effectiveness against the most extreme climatic shocks associated with higher emissions scenarios, which would require reducing dependence on climate-sensitive livelihood activities (Davies *et al.*, 2009; Wiseman *et al.*, 2009; Pelham *et al.*, 2011; Béné *et al.*, 2012). Social protection could further build adaptive capacity if based on improved understanding of the structural causes of poverty, including political and institutional dimensions (Brown *et al.*, 2007; Davies *et al.*, 2009; Levine *et al.*, 2011).

[FOOTNOTE 8: Social protection can include social transfers (cash or food), minimum standards such as for child labor, and social insurance.]

Risk spreading mechanisms used in the African context include kinship networks; community funds; and disaster relief and insurance, which can provide financial security against extreme events such as droughts, floods, and tropical cyclones, and concurrently reduce poverty and enhance adaptive capacity[9] (Leary *et al.*, 2008a; Linnerooth-Bayer *et al.* 2009; Coe and Stern, 2011). Recent developments include the emergence of index-based insurance contracts (Box 22-1), which pay out not with the actual loss, but with a measurable event that could cause loss.

[FOOTNOTE 9: Climate (or disaster) risk financing instruments include contingency funds; agricultural and property (private) insurance; sovereign insurance; reallocation of program expenditures; weather derivatives; and bonds.]

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Box 22-1. Experience with Index-Based Weather Insurance in Africa

Malawi's initial experience of dealing with drought risk through index-based weather insurance directly to smallholders appears positive: 892 farmers purchased the insurance in the first trial period, which was bundled with a loan for groundnut production inputs (Hellmuth *et al.*, 2009). In the next year, the pilot expanded, with the addition of maize, taking numbers up to 1,710 farmers and stimulating interest among banks, financiers, and supply chain participants such as processing and trading companies and input suppliers. A pilot insurance project in Ethiopia was designed to pay claims to the government based on a drought index that uses a time window between observed lack of rain and actual materialization of losses. This allows stakeholders to address threats to food security in ways that prevent the depletion of farmers' productive assets, which reduces the future demand for humanitarian aid by enabling households to produce more food during subsequent seasons (Krishnamurty, 2011).

Another key innovation in Ethiopia is the insurance for work program that allows cash-poor farmers to work for their insurance premiums by engaging in community-identified disaster risk reduction products, such as soil management and improved irrigation (WFP, 2011), which makes insurance affordable to the most marginalized and resource-poor sectors of society.

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The challenges associated with current risk reduction strategies include political and institutional challenges in translating early warning into early action (Bailey, 2013); communication challenges related to EWS: conveying useful information in local languages and communicating EWS in remote areas; national-level mistrust of locally collected data, which are perceived to be inflated to leverage more relief resources (Hellmuth *et al.*, 2007; Pantuliano and Wekesa, 2008; Cartwright *et al.*, 2008; FAO, 2011); the call for improved user-friendliness of early warning information, including at smaller spatial scales; the need for increased capacity in National Meteorological centres (22.4.2); and the need for better linkages between early warning, response, and prevention (Haan *et al.*, 2012).

Evidence is increasing that livelihood diversification, long used by African households to cope with climate shocks, can also assist with building resilience for longer term climate change by spreading risk. Over the past 20 years, households in the Sahel have reduced their vulnerability and increased their wealth through livelihood diversification, particularly when diversifying out of agriculture (Mertz *et al.*, 2011). Households may employ a range of strategies, including on-farm diversification or specialization (Sissoko *et al.*, 2011; Tacoli, 2011). Motsholapheko *et al.* (2011) show how livelihood diversification is used as an adaptation to flooding in the Okavango Delta, Botswana, and Badjeck *et al.* (2010) recommend private and public insurance schemes to help fishing communities rebuild after extreme events, and education and skills upgrading to enable broader choices when fishery activities can no longer be sustained. See Chapter 9 for a fuller discussion of the role of livelihood diversification in adaptation, particularly 9.3.3.1 and 9.3.5.2). Remittances are a longstanding and important means of reducing risk to climate variability and other household stressors, and of contributing to recovery from climatic shocks, as further discussed in Chapter 9 (9.3.3.3, 9.3.5.2).

While livelihood diversification is an important adaptation strategy, it may replace formerly sustainable practices with livelihood activities that have negative environmental impacts (22.4.5.8).

Rural finance and micro-credit can be enabling activities for adaptive response, which are also used by women for resilience-building activities (e.g., as documented in Sudan by Osman-Elasha *et al.*, 2008). Credit and storage systems are instrumental in supporting families during the lean period, to prevent the sale of assets to buy food when market prices are higher (Romero González *et al.*, 2011). Long seen as a fundamental process for most African families to incorporate choice into their risk profile and adapt to climate variability (Goldstone, 2002; Urdal, 2005; Reuveny, 2007; Fox and Hoelscher, 2010), there is evidence in some areas of the increased importance of migration (discussed in section 22.6.1, 8.2, 9.3.3.3, 12.4) and trade for livelihood strategies, as opposed to subsistence agriculture, as shown by Mertz *et al.* (2011) for the Sudano-Sahelian region of West Africa.

22.4.5.3. Adaptation as a Participatory Learning Process

Since AR4, there has been more focus on the importance of flexible and iterative learning approaches for effective adaptation (*medium evidence, high agreement*). Due to the variety of intersecting social, environmental, and economic factors that affect societal adaptation, governments, communities, and individuals (Jones *et al.*, 2010; Jones, 2012), adaptation is increasingly recognized as a complex process involving multiple linked steps at several scales, rather than a series of simple planned technical interventions (Moser and Ekstrom, 2010). Implementing adaptation as a participatory learning process enables people to adopt a proactive or anticipatory stance to avoid ‘learning by shock’ (Tschakert and Dietrich, 2010).

Iterative and experiential learning allows for flexible adaptation planning, appropriate considering the uncertainty inherent in climate projections that is compounded by other sources of flux affecting populations in Africa (Suarez *et al.*, 2008; Dodman and Carmin, 2011; Huq, 2011; Koelle and Annecke, 2011). Many studies have highlighted the utility of participatory action research, social and experiential learning, and creating enabling spaces for multi-stakeholder dialogue for managing uncertainty and unlocking the social and behavioral change required for adaptation (e.g., Tompkins and Adger, 2003; Ziervogel and Opere, 2010; Bizikova *et al.*, 2010; Tschakert and Dietrich 2010; CCAA, 2011; Ebi *et al.*, 2011; UNDP-UNEP Poverty-Environment Initiative, 2011b; Thorn, 2011; Faysse *et al.*, 2012). Transdisciplinary approaches, which hold promise for enhancing linkages between sectors and thus reducing maladaptation are also starting to be adopted, as for example in the urban context (Evans, 2011). Learning approaches for adaptation may involve co-production of knowledge – such as combining local and traditional knowledge with scientific knowledge (22.4.5.4).

Adaptive co-management[10] holds potential to develop capacity to deal with change (Watkiss *et al.*, 2010; Plummer, 2012); the implications of strategic adaptive management for adaptation in aquatic protected areas in South Africa are being explored (Kingsford *et al.*, 2011).

[FOOTNOTE 10: Adaptive co-management is understood as "a process by which institutional arrangements and ecological knowledge are tested and revised in a dynamic, ongoing, self-organized process of learning-by-doing" (Folke *et al.*, 2002).]

Caveats and constraints to viewing adaptation as a participatory learning process include the time and resources required from both local actors and external facilitators, the challenges of multidisciplinary research, the politics of stakeholder participation and the effects of power imbalances, and the need to consider not only the consensus approach but also the role of conflicts (Aylett, 2010; Tschakert and Dietrich, 2010; Beardon and Newman, 2011; Jobbins, 2011; Shankland and Chambote, 2011). Learning throughout the adaptation process necessitates additional emphasis on ways of sharing experiences between communities and other stakeholders, both horizontally and vertically (22.4.5.4). Information and communication technologies, including mobile phones, radio, and the internet, can play a role in facilitating participatory learning processes and helping to overcome some of the challenges (Harvey *et al.*, 2012).

The increased emphasis on the importance of innovation for successful adaptation, in both rural and urban contexts, relates to interventions that employ innovative methods, as well as the innovation role of institutions (Tschakert and Dietrich, 2010; Dodman and Carmin, 2011; Rodima-Taylor, 2012; Scheffran *et al.*, 2012). Scheffran *et al.* (2012) demonstrate how migrant social organizations in the western Sahel initiate innovations across regions by transferring technology and knowledge, as well as remittances and resources. While relevant, high-quality data is important as a basis for adaptation planning, innovative methods are being used to overcome data gaps, particularly local climatic data and analysis capability (Tschakert and Dietrich, 2010; GEF Evaluation Office, 2011).

22.4.5.4. Knowledge Development and Sharing

Recent literature has confirmed the positive role of local and traditional knowledge in building resilience and adaptive capacity, and shaping responses to climatic variability and change in Africa (Nyong *et al.*, 2007; Osbahr *et al.*, 2007; Goulden *et al.*, 2009b; Ifejika Speranza *et al.*, 2010; Jalloh *et al.*, 2011b; Newsham and Thomas, 2011). This is particularly so at the community scale, where there may be limited access to, quality of, or ability to use scientific information. The recent report on extreme events and disasters (IPCC, 2012) supports this view, finding *high agreement* and *robust evidence* of the positive impacts of integrating indigenous and scientific knowledge for adaptation. Concerns about the future adequacy of local knowledge to respond to climate impacts within the multi-stressor context include the decline in intergenerational transmission; a perceived decline in the reliability of local indicators for variability and change, as a result of socio-cultural, environmental, and climate changes (Hitchcock 2009; Jennings and Magrath 2009); and challenges of the emerging and anticipated climatic changes seeming to overrun indigenous knowledge and coping mechanisms of farmers (Berkes, 2009; Ifejika Speranza *et al.*, 2010; Jalloh *et al.*, 2011b; section 22.4.6). Based on analysis of the responses to the Sahel droughts during the 1970s and 1980s, Mortimore (2010) argues that local knowledge systems are more dynamic and robust than is often acknowledged. Linking indigenous and conventional climate observations can add value to climate change adaptation within different local communities in Africa (Roncoli *et al.*, 2002; Nyong *et al.*, 2007; Chang'a *et al.*, 2010; Guthiga and Newsham, 2011).

Choosing specific adaptation actions that are informed by users' perceptions and supported by accurate climate information, relevant to the scale where decisions are made, would be supportive of the largely autonomous adaptation taking place in Africa (Vogel and O'Brien, 2006; Ziervogel *et al.*, 2008; Bryan *et al.*, 2009; Godfrey *et al.*, 2010). Key problems regarding how science can inform decision making and policy are how best to match scientific information, for example about uncertainty of change, with decision needs; how to tailor information to different constituencies; and what criteria to use to assess whether or not information is legitimate to influence policy and decisionmaking (Vogel *et al.*, 2007; Hirsch Hadorn *et al.*, 2008). Institutional innovation is one solution: for example, Nigeria established the Science Committee on Climate Change to develop strategies to bridge the gap between increasing scientific knowledge and policy (Corsi *et al.*, 2012).

There is agreement that culture, or the shaping social norms, values, and rules including those related to ethnicity, class, gender, health, age, social status, cast, and hierarchy, is of crucial importance for adaptive capacity as a positive attribute but also as a barrier to successful local adaptation (22.4.6); further research is required in this field, not least because culture is highly heterogeneous within a society or locality (Adger *et al.*, 2007, 2009; Ensor and Berger, 2009; Nielsen and Reenberg, 2010; Jones, 2012). Studies show that while it is important to further develop the evidence base for the effectiveness of traditional knowledge, integrating cultural components such as stories, myths, and oral history into initiatives to document local and traditional knowledge on adaptive or coping mechanisms is a key to better understanding how climate vulnerability and adaptation are framed and experienced (Urquhart, 2009; Beardon and Newman, 2011; Ford *et al.*, 2012). Appropriate and equitable processes of participation and communication between scientists and local people have been found to prevent misuse or misappropriation of local and scientific knowledge (Nyong *et al.*, 2007; Orlove *et al.*, 2010; Crane, 2010).

While multi-stakeholder platforms promote collaborative adaptation responses (CARE, 2012), adaptation initiatives in Africa lack comprehensive, institutionalised and proactive systems for knowledge sharing (GEF Evaluation Office, 2011; AAP, 2012).

22.4.5.5. Communication, Education, and Capacity Development

Capacity development and awareness raising to enhance understanding of climate impacts and adaptation competencies and engender behavioural change have been undertaken through civil society-driven approaches or by institutions, such as regional and national research institutes, international and national programs and non-governmental organizations (UNFCCC, 2007; Reid *et al.*, 2010; CCAA, 2011; START, 2011; Figueiredo and Perkins, 2012). Promising examples include youth ambassadors in Lesotho and civil society organizations in Tanzania (Corsi *et al.*, 2012), and children as effective communicators and advocates for adaptation-related behavioral and policy change (22.4.3). Progress on inclusion of climate change into formal education is mixed, occurring within the relatively low priority given to environmental education in most countries (UNFCCC, 2007; Corsi *et al.*, 2012; Mukute *et al.*, 2012).

Innovative methods used to communicate climate change include participatory video, photo stories, oral history videos, vernacular drama, radio, television and festivals, with an emphasis on the important rle of the media (Suarez *et al.*, 2008; Harvey, 2011; Chikapa, 2012; Corsi *et al.*, 2012). Better evidence-based communication processes will enhance awareness raising of the diverse range of stakeholders at all levels on the different aspects of climate change (Niang, 2007; Simane *et al.*, 2012). A better understanding of the dimensions of the problem could be achieved by bringing together multiple users and producers of scientific and local knowledgein a trans-disciplinary process (Vogel *et al.*, 2007; Hirsch Hadorn *et al.*, 2008; Ziervogel *et al.*, 2008; Koné *et al.*, 2011)

22.4.5.6. Ecosystem Services, Biodiversity, and Natural Resource Management

Africa's longstanding experiences with natural resource management, biodiversity use, and ecosystem-based responses such as afforestation, rangeland regeneration, catchment rehabilitation and community-based natural resource management (CBNRM) can be harnessed to develop effective and ecologically sustainable local adaptation strategies (*high confidence*). Relevant specific experiences include using mobile grazing to deal with both spatial and temporal rainfall variability in the Sahel (Djoudi *et al.*, 2013); reducing the negative impacts of drought and floods on agricultural and livestock-based livelihoods through forest goods and services in Mali, Tanzania, and Zambia (Robledo *et al.*, 2012); and ensuring food security and improved livelihoods for indigenous and local communities in West and Central Africa through the rich diversity of plant and animal genetic resources (Jalloh *et al.*, 2011b).

Natural resource management (NRM) practices that improve ecosystem resilience can serve as proactive, low regrets adaptation strategies for vulnerable livelihoods (*high confidence*). Two relevant widespread dual-benefit practices, developed to address desertification, are natural regeneration of local trees (Box 22-2) and water harvesting. Water harvesting practices[11] have increased soil organic matter, improved soil structure, and increased agricultural yields at sites in Burkina Faso, Mali, Niger, and elsewhere, and are used by 60% of farmers in one area of Burkina Faso (Fatondji *et al.*, 2009; Vohland and Barry, 2009; Barbier *et al.*, 2009; Larwanou and Saadou, 2011). Although these and other practices serve as adaptations to climate change, revenue generation and other concerns may outweigh climate change as a motivating factor in their adoption (Mertz *et al.*, 2009; Nielsen and Reenberg, 2010). While destocking of livestock during drought periods may also address desertification and adaptation, the lack of individual incentives and marketing mechanisms to destock and other cultural barriers inhibit their widespread adoption in the Sahel (Hein *et al.*, 2009; Nielsen and Reenberg, 2010). Despite these provisos and other constraints (see for example Nelson and Agrawal, 2008; section 22.4.6 further highlights local-level institutional constraints), local stakeholder institutions for CBNRM do enable a more flexible response to changing climatic conditions; CBNRM is also a vehicle for improving links between ecosystem services and poverty reduction, to enable sustainable adaptation approaches (Shackleton *et al.*, 2010; Chishakwe *et al*., 2012; Girot *et al.*, 2012). Based on lessons learned in Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe, Chishakwe *et al.* (2012) point out the synergies between CBNRM and adaptation at the community level, notwithstanding institutional and other constraints experienced with CBNRM.

[FOOTNOTE 11: Water harvesting refers to a collection of traditional practices in which farmers use small planting pits, half-moon berms, rock bunds along contours, and other structures to capture runoff from episodic rain events (Kandji *et al.*, 2006).]

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Box 22-2. African Success Story: Integrating Trees into Annual Cropping Systems

Recent success stories from smallholder systems in Africa illustrate the potential for transforming degraded agricultural landscapes into more productive, sustainable and resilient systems by integrating trees into annual cropping systems. For example, in Zambia and Malawi, an integrated strategy for replenishing soil fertility on degraded lands, which combines planting of nitrogen-fixing *Faidherbia* trees with small doses of mineral fertilizers, has consistently more than doubled yields of maize leading to increased food security and greater income generation (Garrity *et al.*, 2010). In the Sahel, natural regeneration, or the traditional selection and protection of small trees to maturity by farmers and herders has, perhaps for centuries, produced extensive parks of *Acacia albida* (winter thorn) in Senegal (Lericollais, 1989), *Adansonia digitata* (baobab) in West and southern Africa (Sanchez *et al.*, 2011), and *Butyrospermum parkii* (Shea butter) in Burkina Faso (Gijsbers *et al.*, 1994). Recent natural regeneration efforts have increased tree density and species richness at locations in Burkina Faso (Ræbild *et al.*, 2012) and Niger (Larwanou and Saadou, 2011), though adoption and success is somewhat dependent on soil type (Haglund *et al.*, 2011; Larwanou and Saadou, 2011). In southern Niger, farmer-managed natural regeneration of *Faidherbia albida* and other field trees, which began in earnest in the late 1980s, has led to large-scale increase in tree cover across 4.8 million ha, and to decreased sensitivity to drought of the production systems, compared to other regions in Niger (Reij *et al.*, 2009; Tougiani *et al.*, 2009; Sendzimir *et al.*, 2011).

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Differentiation in the literature is growing between ‘hard path’ and ‘soft path’ approaches to adaptation (Sovacool, 2011; Kundzewicz, 2011), with ‘soft path’, low-regrets approaches, such as using intact wetlands for flood risk management, often the first line of defence for poor people in Africa; as contrasted with ‘hard path’ approaches like embankments and dams for flood control (McCully, 2007; Kundzewicz, 2011). Intact ecosystem services and biodiversity are recognized as critical components of successful human adaptation to climate change that may be more effective and incur lower costs than ‘hard’ or engineered solutions (Abramovitz *et al.*, 2002; Petersen and Holness, 2011; UNDP-UNEP Poverty-Environment Initiative, 2011a; Girot et al, 2012; Pramova *et al*., 2012; Roberts *et al.*, 2012; Box 22-2). This provides a compelling reason for linking biodiversity, developmental, and social goals, as taken up, for example, in Djibouti’s NAPA project on mangrove restoration to reduce salt water intrusion and coastal production losses due to climate hazards (Pramova *et al.*, 2012).

The emerging global concept of ecosystem-based adaptation (EbA) provides a system-oriented approach for Africa’s longstanding local NRM practices. Despite the evidence from studies cited in this section, scaling-up to prioritize ecosystem responses and EbA in plans and policy has been slow; a broad understanding that EbA is an integral component of the developmental agenda, rather than a competing ‘green’ agenda, would promote this process. Adaptive environmental governance represents one of the future challenges for the implementation of EbA strategies in Africa, together with sustainable use of resources, secure access to meet needs under climate change, and strong local institutions to enable this (Robledo *et al.*, 2012). Ecosystem-based adaptation could be an important approach to consider for the globally significant Congo Basin forests, particularly given the predominance of REDD+ approaches for this region that risk neglecting adaptation responses, or may result in maladaptation (Somorin *et al.*, 2012; Sonwa *et al.*, 2012; sections 22.4.5.8, 22.6.2). Ecosystem-based approaches are further discussed in WGII Chapter 4, and Box CC-EA.

22.4.5.7. Technological and Infrastructural Adaptation Responses

Since AR4, experience has been gained on technological and infrastructural adaptation in agricultural and water management responses, for climate-proofing infrastructure, and for improved food storage and management to reduce post-harvest losses; this has been increasingly in conjunction with ‘soft’ measures.

There is increased evidence that farmers are changing their production practices in response to increased food security risks linked to climate change and variability, through both technical and behavioural means. Examples include planting cereal crop varieties that are better suited to shorter and more variable growing seasons (Akullo *et al.*, 2007; Thomas *et al.*, 2007; Yesuf *et al.*, 2008; Yaro, 2010; Laube *et al.*, 2012), constructing bunds to more effectively capture rainwater and reduce soil erosion (Nyssen *et al.*, 2007; Thomas *et al.*, 2007; Reij *et al.*, 2009), reduced tillage practices and crop residue management to more effectively bridge dry spells (Ngigi *et al*., 2006; Marongwe *et al.*, 2011), and adjusting planting dates to match shifts in the timing of rainfall (Abou-Hadid, 2006; Vincent *et al.*, 2011b).

Conservation agriculture has good potential to both bolster food production and enable better management of climate risks (*high confidence)* (Verchot *et al.*, 2007; Thomas, 2008; Syampungani *et al.*, 2010; Thierfelder and Wall, 2010; Kassam *et al.*, 2012). Such practices, which include conservation/zero tillage, soil incorporation of crop residues and green manures, building of stone bunds, agroforestry, and afforestation/reforestation of croplands, reduce runoff and protect soils from erosion, increase rainwater capture and soil water-holding capacity, replenish soil fertility, and increase carbon storage in agricultural landscapes. Conservation agriculture systems have potential to lower the costs of tillage and weed control with subsequent increase in net returns, as found in Malawi by Ngwira *et al.* (2012).

Expansion of irrigation in sub-Saharan Africa holds significant potential for spurring agricultural growth while also better managing water deficiency risks associated with climate change (Dillon, 2011; You *et al.*, 2011). Embedding irrigation expansion within systems-level planning that considers the multi-stressor context in which irrigation expansion is occurring can help to ensure that efforts to promote irrigation can be sustained and do not instead generate a new set of hurdles for producers or engender conflict (van de Giesen *et al.*, 2010; Burney and Naylor, 2012; Laube *et al.*, 2012). Suitable approaches to expand irrigation in Africa include using low-pressure drip irrigation technologies and construction of small reservoirs, both of which can help to foster diversification toward irrigated high-value horticultural crops (Karlberg *et al.*, 2007; Woltering *et al.*, 2011; Biazin *et al.*, 2012). If drought risk increases and rainfall patterns change, adaptation in agricultural water management would be enhanced through a strategic approach that encompasses overall water use efficiency for both rainfed and irrigated production (Weiβ *et al.*, 2009), embeds irrigation expansion efforts within a larger rural development context that includes increased access to agricultural inputs and markets (You *et al.*, 2011; Burney and Naylor, 2012), and that involves an integrated suite of options (e.g., plant breeding and improved pest and disease and soil fertility management, and *in situ* rainwater harvesting) to increase water productivity (Passioura, 2006; Biazin *et al.*, 2012).

Experience has been gained since the AR4 on adaptation of infrastructure (transportation, buildings, food storage, coastal), with evidence that this can sometimes be achieved at low cost, and additional implementation of soft measures such as building codes and zone planning (UNFCCC, 2007; Halsnæs and and Trarup, 2009; Urquhart, 2009; UN-Habitat and UNEP, 2010; AfDB, 2011; Mosha, 2011; Siegel, 2011; Corsi *et al.*, 2012). Examples of adaptation actions for road and transportation infrastructure include submersible roads in Madagascar and building dikes to avoid flooding in Djibouti (UNFCCC, 2007; Urquhart, 2009). Infrastructural climate change impact assessments and enhanced construction and infrastructural standards - such as raising foundations of buildings, strengthening roads, and increasing storm water drainage capacity - are steps to safeguard buildings in vulnerable locations or with inadequate construction (UN-Habitat and UNEP, 2010; Mosha, 2011; Corsi *et al.*, 2012). Mainstreaming adaptation into infrastructure development can be achieved at low cost, as has been shown for flood-prone roads in Mozambique (Halsnæs and and Trarup, 2009). Integrating climate change considerations into infrastructure at the design stage is preferable from a cost and feasibility perspective than trying to retrofit infrastructure (Chigwada, 2005; Siegel, 2011). Softer measures, such as building codes and zone planning are being implemented and are needed to complement and/or provide strategic guidance for hard infrastructural climate proofing, for example, the adoption of cyclone-resistant standards for public buildings in Madagascar (AfDB, 2011). Research in South Africa has recognized that the best option for adaptation in the coastal zone is not to combat coastal erosion in the long term, but rather to allow progression of the natural processes (Naidu *et al.*, 2006; Zitholele Consulting, 2009).

Reducing post-harvest losses through improved food storage, food preservation, greater access to processing facilities, and improved systems of transportation to markets are important means to enhance food security (Brown *et al.*, 2009; Godfray *et al.*, 2010; Codjoe and Owusu 2011). Low cost farm-level storage options, such as metal silos (Tefera *et al.*, 2011), and triple-sealed plastic bags (Baoua *et al.*, 2012) are effective for reducing post-harvest losses from pests and pathogens. Better storage allows farmers greater flexibility in when they sell their grain, with related income benefits (Brown *et al.*, 2009), and reduces post-harvest infection of grain by aflatoxins, which is widespread in Africa and increases with drought stress and high humidity during storage (Cotty and Jaime-Garcia, 2007; Shephard, 2008).

22.4.5.8. Maladaptation Risks

The literature increasingly highlights the need, when designing development or adaptation research, policies and initiatives, to adopt a longer-term view and to consider the multi-stressor context in which people live, in order to avoid maladaptation, or outcomes that may serve short-term goals but come with future costs to society (refer to Glossary). The short-term nature of policy and other interventions, especially if they favor economic growth and modernization over resilience and human security, may themselves act as stressors or allow people to only react to short-term climate variability (Bryan *et al.*, 2009; Brooks *et al.*, 2009; Bunce *et al.*, 2010a; Levine et al, 2011). The political context can also undermine autonomous adaptation and lead to maladaptation; for instance, Smucker and Wisner (2008) found that political and economic changes in Kenya meant that farmers could no longer use traditional strategies for coping with climatic shocks and stressors, with the poorest increasingly having to resort to coping strategies that undermined their long-term livelihood security, also known as erosive coping, such as more intensive grazing of livestock and shorter crop rotations (van der Geest and Dietz, 2004). In a case from the Simiyu wetlands in Tanzania, Hamisi *et al.* (2012) find that coping and reactive adaptation strategies may lead to maladaptation – for instance, through negative impacts on natural vegetation because of increased intensity of farming in wetter parts of the floodplain, where farmers have moved to exploit the higher soil water content.

Some diversification strategies, such as charcoal production and artisanal mining, may increase risk through promoting ecological change and the loss of ecosystem services to fall back on (Paavola, 2008; Adger et al, 2011; Shackleton and Shackleton, 2012). Studies also highlight risks that traditional adaptive pastoralism systems may be replaced by maladaptive activities. For example, charcoal production has become a major source of income for 70% of poor and middle-income pastoralists in some areas of Somaliland, with resultant deforestation (Hartmann and Sugulle, 2009).

Another example of maladaptation provided in the literature is the potential long-term hydro-dependency risks and threats to ecosystem health and community resilience as a result of increased dam building in Africa, which may be underpinned by policies of multi-lateral donors (Avery, 2012; Beilfuss, 2012; Jones *et al*., 2012). While increased rainwater storage will assist with buffering dry periods, and hydropower can play a key role in ending energy poverty, it is important that this is designed to promote environmental and social sustainability; that costs and benefits are equitably shared; and that water storage and energy generation infrastructure is itself climate proofed. Additional substantive review of such international development projects would assist in assuring that these do not result in maladaptation. See WGII Chapter 4 for a discussion of the unwanted consequences of building more and larger impoundments and increased water abstraction on terrestrial and freshwater ecosystems; health aspects of this are noted in sections 22.3.5.1 and 22.3.5.4. See section 22.6.2 on avoiding undesirable trade-offs between REDD+ approaches and adaptation that have the potential to result in significant maladaptation.

22.4.6. Barriers and Limits to Adaptation in Africa

A complex web of interacting barriers to local-level adaptation exists that manifests from national to local scales to constrain adaptation, which includes institutional, political, social, cultural, biophysical, cognitive and behavioral, and gender-related (*high confidence*). While relatively few studies from Africa have focused specifically on barriers and limits to adaptation, perceived and experienced constraints distilled from the literature encompass the resources needed for adaptation, the factors influencing adaptive capacity, the reasons for not employing particular adaptive strategies or not responding to climate change signals, and the reasons why some groups or individuals adapt but not others (Roncoli *et al.*, 2010; Bryan *et al.*, 2011; Nyanga *et al.*, 2011; Ludi *et al.*, 2012).

At the local level, institutional barriers hamper adaptation through elite capture and corruption; poor survival of institutions without social roots; and lack of attention to the institutional requirements of new technological interventions (Ludi *et al.*, 2012). Tenure security over land and vital assets is widely accepted as being crucial for enabling people to make longer-term and forward-looking decisions in the face of uncertainty, such as changing farming practices, farming systems, or even transforming livelihoods altogether (Bryan *et al.*, 2009; Brown *et al.*, 2010; Romero González *et al.*, 2011). In addition to unclear land tenure, legislation forbidding ecosystem use is one of the issues strengthening underlying conflicts over resources in Africa; resolving this would enable ecosystems to contribute to adaptation beyond short-term coping (Robledo *et al.*, 2012). There is also evidence that innovation may be suppressed if the dominant culture disapproves of departure from the ‘normal way of doing things’ (Ludi *et al.*, 2012; Jones 2012).

Characteristics such as wealth, gender, ethnicity, religion, class, caste, or profession can act as social barriers for some to adapt successfully or acquire the required adaptive capacities (Ziervogel *et al.*, 2008; Godfrey *et al.* 2010; Jones and Boyd, 2011). Based on field research conducted in the Borana area of southern Ethiopia, Debsu (2012) highlights the complex way in which external interventions may affect local and indigenous institutions by strengthening some coping and adaptive mechanisms and weakening others. Restrictive institutions can block attempts to enhance local adaptive capacity by maintaining structural inequities related to gender and ethnic minorities (Jones, 2012). Constraints faced by women, often through customs and legal barriers, include limited access to land and natural resources; lack of credit and input in decisionmaking, limited ability to take financial risk, lack of confidence, limited access to information and new ideas, and under-valuation of women’s opinions

(McFerson, 2010; Peach Brown, 2011, Djoudi and Brockhaus 2011; Jones 2012; Ludi *et al.*, 2012; Goh, 2012; Codjoe *et al.* 2012).

Few small-scale farmers across Africa are able to adapt to climatic changes, while others are restricted by a suite of overlapping barriers (*high agreement, robust evidence*). Constraints identified in Kenya, South Africa, Ethiopia, Malawi, Mozambique, Zimbabwe, Zambia and Ghana included poverty and a lack of cash or credit (financial barriers); limited access to water and land, poor soil quality, land fragmentation, poor roads, and pests and diseases (biophysical and infrastructural barriers); lack of access to inputs, shortage of labor, poor quality of seed and inputs attributed to a lack of quality controls by government and corrupt business practices by traders, insecure tenure, and poor market access (institutional, technological, and political barriers); and finally a lack of information on agroforestry/afforestation, different crop varieties, climate change predictions and weather, and adaptation strategies (informational barriers) (Bryan *et al.* 2009, 2011; Barbier *et al.*, 2009; Clover and Eriksen, 2009; Deressa *et al.*, 2009; Roncoli *et al.*, 2010; Mandleni and Anim, 2011; Nhemachena and Hassan, 2011; Nyanga *et al.*,2011; Vincent *et al.*, 2011a).

Recognition is increasing that understanding psychological factors such as mindsets and risk perceptions is crucial for supporting adaptation (Grothmann and Patt, 2005; Patt and Schröter, 2008; Jones, 2012). Cognitive barriers to adaptation include alternative explanations of extreme events and weather such as religion (God's will), the ancestors, and witchcraft, or seeing these changes as out of people's own control (Byran *et al.*, 2009; Roncoli *et al.*, 2010; Mandleni and Anim, 2011; Artur and Hilhorst, 2012; Jones, 2012; Mubaya *et al.* 2012).

Climate uncertainty, high levels of variability, lack of access to appropriate real-time and future climate information, and poor predictive capacity at a local scale are commonly cited barriers to adaptation from the individual to national level (Repetto, 2008; Dinku *et al.*, 2011; Jones, 2012; Mather and Stretch, 2012). Despite the cultural and psychological barriers noted above, several studies have shown that farmers with access to climate information are more predisposed to adjust their behaviour in response to perceived climate changes (Mubaya *et al.*, 2012).

At a policy level, studies have detected political, institutional and discursive barriers to adaptation. Adaptation options in southern Africa have been blocked by political and institutional inefficiencies, lack of prioritization of climate change, and the dominance of other discourses, such as the mitigation discourse in South Africa and short-term disaster-focused views of climate variability (Madzwamuse, 2010; Bele *et al.*, 2011; Berrang-Ford *et al.*, 2011; Conway and Schipper, 2011; Kalame *et al.*, 2011; Chevallier, 2012; Toteng, 2012; Leck *et al.*, 2012). Lack of local participation in policy formulation, the neglect of social and cultural context, and the inadvertent undermining of local coping and adaptive strategies have also been identified by several commentators as barriers to appropriate national policies and frameworks that would support local-level adaptation (e.g., Brockhaus and Djoudi, 2008; Bele *et al.*, 2011; Chevallier, 2012).

Many of these constraints to adaptation are well entrenched and will be far from easy to overcome; some may act as limits to adaptation for particular social groups (*high confidence)*. Biophysical barriers to adaptation in the arid areas could present as limits for more vulnerable groups if current climate change trends continue (Leary *et al.*, 2008b; Sallu *et al.*, 2010; Roncoli *et al.*, 2010). Traditional and autonomous adaptation strategies, particularly in the drylands, have been constrained by social-ecological change and drivers such as population growth, land privatization, land degradation, widespread poverty, HIV/AIDS, poorly conceived policies and modernization, obstacles to mobility and use of indigenous knowledge, as well as erosion of traditional knowledge, to the extent that it is difficult or no longer possible to respond to climate variability and risk in ways that people did in the past (Leary *et al.*, 2008b; Dabi *et al.*, 2008; Paavola, 2008; Smucker and Wisner, 2008; Clover and Eriksen, 2009; Conway, 2009; UNCCD *et al.*, 2009; Bunce *et al.*, 2010b; Quinn *et al.*, 2011; Jones, 2012; section 22.4.5.4). As a result of these multiple stressors working together, the number of response options has decreased and traditional coping strategies are no longer sufficient (Dube and Sekhwela, 2008). Studies have shown that most autonomous adaptation usually involves minor adjustments to current practices (e.g. changes in planting decisions); there are simply too many barriers to implementing substantial changes that require investment (e.g., agroforestry and irrigation) (Bryan *et al.*, 2011). Such adaptation strategies would be enhanced through government and private sector/NGO support, without which many poor groups in Africa may face real limits to adaptation (Vincent *et al.*, 2011a; Jones, 2012).

These findings highlight the benefits of transformational change in situations where high levels of vulnerability and low adaptive capacity detract from the possibility for systems to adapt sustainably. This is in agreement with the Special Report on Extreme Events, which additionally found *high agreement* and *robust evidence* for the importance of a spectrum of actions ranging from incremental steps to transformational changes in order to reduce climate risks (IPCC, 2012). In support of such solutions, Moench (2011) has called for distilling common principles for building adaptive capacity at different stages, and adaptive management and learning are seen as critical approaches for facilitating transformation (Section 22.4.5.3; IPCC, 2012). Chapter 16 provides further discussion on how encountering limits to adaptation may trigger transformational change, which can be a means of adapting to hard limits.

22.5. Key Risks for Africa

Table 22-6 highlights key risks for Africa (see also Table 19-4 and CC-KR), as identified through assessment of the literature and expert judgement of the author team, with supporting evaluation of evidence and agreement in the sections of this chapter, as referenced in the caption.

[INSERT TABLE 22-6 HERE
Table 22-6: Key risks from climate change and the potential for risk reduction through mitigation and adaptation in Africa. Key risks are identified based on assessment of the literature and expert judgments made by authors of the various WGII AR5 chapters, with supporting evaluation of evidence and agreement in the referenced chapter sections. Each key risk is characterized as very low, low, medium, high, or very high. Risk levels are presented for the near-term era of committed climate change (here, for 2030-2040), in which projected levels of global mean temperature increase do not diverge substantially across emissions scenarios. Risk levels are also presented for the longer-term era of climate options (here, for 2080-2100), for global mean temperature increase of 2°C and 4°C above preindustrial levels. For each timeframe, risk levels are estimated for the current state of adaptation and for a hypothetical highly adapted state. As the assessment considers potential impacts on different physical, biological, and human systems, risk levels should not necessarily be used to evaluate relative risk across key risks. Relevant climate variables are indicated by symbols.]

As indicated in Table 22-6, seven of the nine key regional risks are assessed for the present as being either medium or high under current adaptation levels, reflecting both the severity of multiple relevant stressors and Africa's existing adaptation deficit. This is the case for risks relating to shifts in biome distribution (22.3.2.1), degradation of coral reefs (22.3.2.3), reduced crop productivity (22.3.4.1), adverse effects on livestock (22.3.4.2), vector- and water-borne diseases (22.3.5.2, 22.3.5.4), under nutrition (22.3.5.3), and migration (22.6.1.2). This assessment indicates that allowing current emissions levels to result in a +4°C world (above pre-industrial levels) by the 2080-2100 period would have negative impacts on Africa's food security, as even under high adaptation levels, risks of reduced crop productivity and adverse effects on livestock are assessed as remaining very high. Moreover, our assessment is that even if high levels of adaptation were achieved, risks of stress on water resources (22.3.3), degradation of coral reefs (22.3.2.3), and the destructive effects of sea level rise and extreme weather events (22.3.6) would remain high. However, even under a lower emissions scenario leading to a long-term 2°C warming, all nine key regional risks are assessed as remaining high or very high under current levels of adaptation. The assessment indicates that even under high adaptation, residual impacts in a 2°C world would be significant, with only risk associated with migration rated as being capable of reduction to low under high levels of adaptation. High adaptation would be enabled by concerted effort and substantial funding; even if this is realized, no risk is assessed as being capable of reduction to below medium status.

22.6. Emerging Issues

22.6.1. Human Security

Although the significance of human security cannot be overestimated, the evidence of the impact of climate change on human security in Africa is disputable (see Chapters 12 and 19). Adverse climate events potentially impact all aspects of human security, either directly or indirectly (on mapping climate security vulnerability in Africa see Busby *et al*., 2013). Food security, water stress, land use and, health security, violent conflict, changing migration patterns, and human settlements are interrelating issues of discussions between climate change and human security. Violent conflict and migration are discussed below (for further details see Chapter 12).

22.6.1.1 Violent Conflict

While there seems to be consensus that the environment is only one of several interconnected causes of conflict and is rarely considered to be the most decisive factor (Kolmannskog, 2010), it remains disputed whether, and if so, how, the changing climate directly increases the risk of violent conflict in Africa (for more details see also Chapters 12 and 19, in particular 12.5.1; 19.4; Gleditsch, 2012). However, views are emerging that there is a positive relationship between increases in temperature and increases in human conflict (Hsiang *et al*., 2013). Some of the factors which may increase the risk of violent conflict, such as low per capita incomes, economic contraction and inconsistent state institutions are sensitive to climate change (12.5.1). For the African Sahel States it has been argued that the propensity for communal conflict across ethnic groups within Africa is influenced by political and economic vulnerability to climate change (Raleigh, 2010). Evidence on the question of whether, and if so to what extent, climate change and variability increases the risk of civil war in Africa is contested (Burke *et al.*, 2009b; Buhaug, 2010; Devitt and Tol, 2012). It has been suggested that due to the depletion of natural resources in Africa as a result of overexploitation and the impact of climate change on environmental degradation, competition for scarce resources could increase and lead to violent conflict (Kumssa and Jones, 2010). For East Africa it has been suggested that increased levels of malnutrition are related to armed conflicts (Rowhani *et al.*, 2011). There is some agreement that rainfall variation has an inconsistent relationship to conflict: both higher and lower anomalous rainfall is associated with increased communal conflict levels; although dry conditions have a lesser effect (Raleigh and Kniveton, 2012; Hendrix and Salehyan 2012; Theisen 2012).

22.6.1.2 Migration

Human migration has social, political, demographic, economic and environmental drivers, which may operate independently or in combination (for more in-depth discussions see Chapters 12.4 and 19.4.2.1; Perch-Nielsen *et al.*, 2008; Piguet, 2010; Foresight, 2011; Piguet *et al.*, 2011; Black *et al.*, 2011a; Van der Geest, 2011). Many of these drivers are climate sensitive (Black *et al.*, 2011c; 12.4.1.). People migrate either temporarily or permanently, within their country or across borders (12.4.1.2; Figure 12-1; Table 12-3; Warner *et al.*, 2010; Kälin and Schrepfer, 2012). The evidence base in the field of migration in Africa is both varied and patchy. Evidence suggests that migration is a strategy to adapt to climate change (12.4.2). Mobility is indeed a strategy (not a reaction) to high levels of climatic variation that is characteristic of Africa (Tacoli, 2011) and the specifics of the response are determined by the economic context of the specific communities.

Besides low-lying islands and coastal and deltaic regions in general, sub-Saharan Africa is one of the regions that would particularly be affected by environmentally induced migration (Gemenne, 2011a). Case studies from Somalia and Burundi emphasize the interaction of climate change, disaster, conflict, displacement, and migration (Kolmannskog, 2010). In Ghana for example, an African country with few conflicts caused by political, ethnic, or religious tensions, and thus with migration drivers more likely related to economic and environmental motivators (Tschakert and Tutu, 2010), some different types of migration flows are considered to have different sensitivity to climate change (Black *et al.*, 2011a). The floods of the Zambezi River in Mozambique in 2008 have displaced 90,000 people, and it has been observed that along the Zambezi River Valley, with approximately 1 million people living in the flood-affected areas, temporary mass displacement is taking on permanent characteristics (Jäger *et al.*, 2009; Warner *et al.*, 2010).

Different assessments of future trends have recently produced contradictory conclusions (e.g., UN-OCAH and IDMC, 2009; Naude, 2010; ADB, 2011; Tacoli, 2011, IDMC, 2011). One approach in assessing future migration potentials, with considerable relevance to the African context, focused on capturing the net effect of environmental change on aggregate migration through analysis of both its interactions with other migration drivers and the role of migration within adaptation strategies, rather than identifying specific groups as potential 'environmental migrants' (Foresight, 2011). Even if Africa's population doubles by 2050 to 2 billion (Lutz and K.C., 2010) and the potential for displacement rises as a consequence of the impact of extreme weather events, recent analyses (Foresight, 2011; Black *et al.*, 2011b) show that the picture for future migration is much more complex than previous assessments of a rise in climate induced migration suggest, and relates to the intersection of multiple drivers with rates of global growth, levels of governance, and climate change.

The empirical base for major migration consequences is weak (Lilleør and Van den Broeck, 2011; Black *et al.*, 2011a; Gemenne, 2011b) and non-existent for international migration patterns (Marchiori *et al.*, 2011). Even across the same type of extreme weather event, the responses can vary (Findlay, 2011; Gray, 2011 for Kenya and Uganda; Raleigh, 2011 for the African Sahel States)).

22.6.2. Integrated Adaptation / Mitigation Approaches

Relevant experience gained in Africa since AR4 in implementing integrated adaptation–mitigation responses within a pro-poor orientation that leverages developmental benefits encompasses some participation of farmers and local communities in carbon offset systems, increasing the use of relevant technologies such as agroforestry and farmer-assisted tree regeneration (22.4.5.6), and emerging Green Economy policy responses. The recognition that adaptation and mitigation are complementary elements of the global response to climate change, and not trade-offs, is gaining traction in Africa (Goklany, 2007; Nyong *et al.*, 2007; UNCCD *et al.*, 2009; Woodfine, 2009; Jalloh *et al.*, 2011b; Milder *et al.*, 2011).

While the suitability of on- and off-farm techniques for an integrated adaptation-mitigation response depends on local physical conditions as well as political and institutional factors, sustainable land management techniques are particularly beneficial for an integrated response in Africa; these include agroforestry, including through farmer-managed natural regeneration; and conservation agriculture (Woodfine, 2009; Milder *et al.*, 2011; Mutonyi and Fungo, 2011; section 22.4.5.6; Box 22-2). An emerging area is multiple-benefit initiatives that aim to reduce poverty, promote adaptation through restoring local ecosystems, and deliver benefits from carbon markets. Brown *et al.*, (2011) note the example of a community-based project in Humbo, Ethiopia, which is facilitating adaptation and generating temporary certified emissions reductions under the Clean Development Mechanism, by restoration of degraded native forests (2,728 ha) through farmer-managed natural regeneration.

The key role of local communities in carbon offset systems through community forestry entails land use flexibility (Purdon, 2010), but can be constrained by the lack of supportive policy environments – for example, for conservation agriculture (Milder *et al.*, 2011).

The literature highlights the desirability of responding to climate change through integrated adaptation–mitigation approaches, including through spatial planning, in the implementation of REDD+ in Africa, especially given the significant contribution to food security and livelihoods of forest systems (Bwango *et al.*, 2000; Guariguata et al., 2008; Nkem *et al.*, 2007; Nasi *et al.*, 2008; Biesbroek *et al.*, 2009; Somorin *et al.*, 2012). However, forests are mainly used for reactive coping and not anticipatory adaptation; studies show that governments favour mitigation while local communities prioritise adaptation (Fisher *et al.*, 2010; Somorin *et al.*, 2012). Flexible REDD+ models that include agriculture and adaptation hold promise for generating co-benefits for poverty reduction, given food security and adaptation priorities, and help to avoid trade-offs between REDD+ implementation and adaptive capacities of communities, ecosystems, and nations (Nkem *et al.*, 2008; Thomson *et al.*, 2010; CIFOR, 2011; Richard *et al.*, 2011; Wertz-Kanounnikoff *et al.*, 2011).

Integrated adaptation–mitigation responses are being considered within the context of the emerging Green Economy discussions. African leaders agreed in 2011 to develop an African Green Growth Strategy, to build a shared vision for promoting sustainable low-carbon growth through a linked adaptation–mitigation approach, with adaptation seen as an urgent priority. A national example is the launch of Ethiopia's Climate Resilient Green Economy Facility in 2012 (Corsi *et al.*, 2012).

22.6.3. Biofuels and Land Use

The potential for first-generation biofuel production in Africa, derived from bioethanol from starch sources and biodiesel production from oilseeds, is significant given the continent's extensive arable lands, labor availability, and favorable climate for biofuel crop production (Amigun *et al.*, 2011; Arndt *et al.*, 2011; Hanff *et al.*, 2011). While biofuel production has positive energy security and economic growth implications, the prospect of wide-scale biofuel production in Africa carries with it significant risks related to about environmental and social sustainability. Among the concerns are competition for land and water between fuel and food crops, adverse impacts of biofuels on biodiversity and the environment, contractual and regulatory obligations that expose farmers to legal risks, changes in land tenure security, and reduced livelihood opportunities for women, pastoralists and migrant farmers who depend on access to the land resource base (Unruh, 2008; Amigun *et al.*, 2011; German *et al.*, 2011; Schoneveld *et al.*, 2011).

More research is needed to understand fully the socioeconomic and environmental tradeoffs associated with biofuel production in Africa. One critical knowledge gap concerns the effect of biofuel production, particularly large-scale schemes, on land use change and subsequent food and livelihood security. For example, the conversion of marginal lands to biofuel crop production would impact the ability of users of these lands (pastoralists and in some cases women who are allocated marginal land for food and medicinal production) to participate in land use and food production decisions (Amigun *et al.*, 2011; Schoneveld *et al.*, 2011). In addition, biofuel production could potentially lead to the extension of agriculture into forested areas, either directly through conversion of fallow vegetation or the opening of mature woodland, or indirectly through use of these lands to offset food crop displacement (German *et al.*, 2011). Such land use conversion would result in biofuel production reducing terrestrial carbon storage potential (Vang Rasmussen *et al.*, 2012a; Vang Rasmussen *et al.*, 2012b).

Better agronomic characterization of biofuel crops is another key knowledge gap. For example, little information exists with respect to the agronomic characteristics of the oilseed crop Jatropha (*Jatropha curcas*) under conditions of intensive cultivation across differing growing environments, despite the fact that Jatropha has been widely touted as an appropriate feedstock for biofuel production in Africa because of its ability to grow in a wide range of climates and soils. Oilseed yields of Jatropha can be highly variable, and even basic information about yield potential and water and fertilizer requirements for producing economically significant oilseed yields is scanty (Achten *et al.*, 2008; Peters and Thielmann, 2008; Hanff *et al.*, 2011). Such knowledge would not only provide a basis for better crop management but would also help to gain better estimates of the extent of water consumption for biofuel production in the context of non-biofuel water-use needs across landscapes. Assessments of Jatropha's potential as an invasive species and its potential allelopathic effects on native vegetation are also needed, in light of the fact that some countries have designated Jatropha as an invasive species (Achten *et al.*, 2008).

22.6.4. Climate Finance and Management

Recent analyses emphasise the significant financial resources and technological support needed to both address Africa's current adaptation deficit and to protect rural and urban livelihoods, societies and economies from climate change impacts at different local scales, with estimates of adaptation costs between US$20-30 billion per annum over the next couple of decades, up to US$60 billion per annum by 2030 (for example see figure 22.6), although these figures are *likely* to be under-estimates, as studies upon which these estimates are based do not always include the costs of overcoming Africa's current adaptation deficit, may be run for one scenario at a time, and do not factor in a range of uncertainties in the planning environment (Parry et al, 2009b; Fankhauser and Schmidt-Traub, 2010; Watkiss et al, 2010; AfDB, 2011; Dodman and Carmin, 2011; LDC Expert Group, 2011; Smith et al, 2011).

Damages related to climate change may affect economic growth and the ability to trade (Lecocq and Shalizi, 2007; Ruppel and Ruppel-Schlichting, 2012). Costs of adaptation and negative economic impacts of climate change have been referred to in sections 22.3.4.4 and 22.3.6; Warner *et al*. (2012) have highlighted the residual impacts of climate change that would occur after adaptation, for case studies in Kenya and The Gambia. The following examples are illustrative of the move to discuss financial implications in the literature.

Scenarios for Tanzania, where agriculture accounts for about half of gross production and employs about 80% of the labor force (Thurlow and Wobst, 2003), project that changes in the mean and extremes of climate variables, could increase poverty vulnerability (Ahmed *et al*., 2011). Scenarios for Namibia based on a computable general equilibrium model project that annual losses to the economy ascribed to the impacts of climate change on the country’s natural resources could range between 1.0% and 4.8% of GDP (Reid *et al.*, 2008). Ghana’s agricultural and economic sector with cocoa being the single most important export product is particularly vulnerable, since cocoa is prone to the effects of a changing climate (Black *et al.*, 2011c), which has been central to the country’s debates on development and poverty alleviation strategies (WTO Trade Policy Review, 2008).

The potential for adaptation to reduce the risks associated with sea level rise is substantial for cumulative land loss and for numbers of people flooded or forced to migrate, with adaptation costs lower than the economic and social damages expected if nothing is done (Kebede *et al.*, 2010).See Figure 22-6.

[INSERT FIGURE 22-6 HERE
Figure 22-6: Total additional costs of adaptation per year from 2000 to 2100 for Tanzania (including beach nourishment and sea and river dikes). The values do not consider the existing adaptation deficit (values in $US 2005, without discounting Source: Kebede *et al.*, 2010.]

The Dynamic Interactive Vulnerability Assessment (DIVA) model was used to assess the monetary and non-monetary impacts of sea level rise on the entire coast (3,461 km) of Tanzania. Under the B1 low-range sea level rise scenario it was estimated that by 2030, a total area of 3,579 to 7,624 km^2 would be lost, mainly through inundation; with around 234,000 to 1.6 million people per year who could potentially experience flooding. Without adaptation, residual damages have been estimated at between US$ 26 and 55 million per year (Kebede *et al*., 2010). Table 22-7 shows the economic impacts of land inundated in Cape Town based on different sea level rise scenarios.

[INSERT TABLE 22-7 HERE
Table 22-7: Land inundated and economic impacts in Cape Town based on a risk assessment (Cartwright, 2008).]

In line with increasing international impetus for adaptation (Persson *et al.*, 2009) the Parties to the UNFCCC agreed on providing “adequate, predictable and sustainable financial resources” for adaptation in developing countries, and, within this context, paid special attention to Africa which is “particularly vulnerable” to the adverse effects of climate change (UNFCCC, 2009; UNFCCC, 2011; Berenter, 2012). Doubts remain about how private sector financing can be effectively mobilized and channeled toward adaptation in developing countries (Atteridge, 2011; Naidoo *et al.*, 2012). The 2012 Landscape of Climate Finance Report (Buchner *et al.*, 2012) stated that mitigation activities attracted US$ 350 billion, mostly related to renewable energy and energy efficiency, while adaptation activities attracted US$ 14 billion. Approximately 30% of the global distributed adaptation finance went to Africa (Nakhooda *et al.*, 2011) and seems to prioritize the continent (Naidoo *et al.*, 2012). However, it is being questioned, whether the adaptation funding that is currently delivered does fulfill demonstrated needs (Flåm and Skjærseth, 2009; Denton, 2010 for sub-Saharan Africa Nakhooda *et al.*, 2011).

Effective adaptation requires more than sufficient levels of funding. It requires developing country ‘readiness,’ which includes abilities to plan and access finances; the capacity to deliver adaptation projects and programs, and to monitor, report, and evaluate their effectiveness (Vandeweerd *et al.*, 2012); and also a regulatory framework, which guarantees e.g. property rights (IPCC AR5 WGIII Draft 2 Chapter 16 p.:27; line 30-33). Particularly serious challenges are associated with directing finance to the sectors and people most vulnerable to climate change

(Denton, 2010; Nakhooda *et al.*, 2011; Pauw *et al.*, 2012). The risk of fund mismanagement with regard to climate finance and adaptation funds needs to be borne in mind. Suggestions to address adequately the level of complexity, uncertainty, and novelty that surrounds many climate finance issues *inter alia* include longer-term and integrated programs rather than isolated projects; building capacity and institutions in African countries (Nakhooda *et al.*, 2011; Pauw *et al.*, 2012); identifying priorities, processes, and knowledge needs at the local level (Haites, 2011; Pauw, 2013); and, accordingly, developing grassroots projects (Fankhauser and Burton, 2011).

22.7. Research Gaps

Research has a key role to play in providing information for informed decisionmaking at local to national levels (Fankhauser, 1997; Ziervogel *et al.*, 2008; Arendse and Crane, 2010). While there is significant activity in African research institutions, much African research capacity is spent on foreign-led research that may necessarily prioritize addressing national knowledge gaps about climate change (Madzwamuse, 2010), and African research may lack merited policy uptake or global recognition as it is often not published in peer-reviewed literature (Denton *et al.*, 2011).

The following overarching data and research gaps have been identified also see Table 22.8:

- Data management and monitoring of climate and hydroclimate parameters and development of climate change scenarios as well as monitoring systems to address climate change impacts in the different sectors (for example the impacts of pests and diseases on crops and livestock) and systems;
- Research and improved methodologies to assess and quantify the impact of climate change on different sectors and systems.
- Socio-economic consequences of the loss of ecosystems and also of economic activities as well as of certain choices in terms of mitigation (biofuels and their links with food and livelihood security for example) and adaptation to climate change;
- The links influence of climate change in emerging issues such as migration and urban food security;
- Developing tools allowing decision makers to make their decisions based on the complexity of the world under climate change, taking into consideration gender, age and all regarding the contribution of local communities.

[INSERT TABLE 22-8 HERE
Table 22-8: Research gaps in different sectors.]

Frequently Asked Questions

FAQ 22.1: How could climate change impact food security in Africa? *[to be inserted in Section 22.3.4.5]*
Food security is comprised of availability (is enough food produced), access (can people get it, and afford it), utilization (how local conditions bear on peoples nutritional uptake from food), and stability (is the supply and access ensured). Strong consensus exists that climate change will have a significantly negative impact on all these aspects of food security in Africa.

Food availability could be threatened through direct climate impacts on crops and livestock from increased flooding, drought, shifts in the timing and amount of rainfall, and high temperatures, or indirectly through increased soil erosion from more frequent heavy storms or through increased pest and disease pressure on crops and livestock caused by warmer temperatures and other changes in climatic conditions. Food access could be threatened by climate change impacts on productivity in important cereal-producing regions of the world which, along with other factors, could raise food prices and erode the ability of the poor in Africa to afford purchased food. Access is also threatened by extreme events that impair food transport and other food system infrastructure. Climate change could impact food utilization through increased disease burden that reduces the ability of the human body to absorb nutrients from food. Warmer and more humid conditions caused by climate change could impact food availability and utilization through increased risk of spoilage of fresh food and pest and pathogen damage to stored foods (cereals, pulses, tubers) that reduces both food availability and quality. Stability could be affected by changes in availability and access that are linked to climatic and other factors.

FAQ 22.2: What role does climate change play with regard to violent conflict in Africa?
[to be inserted in Section 22.6.1.1]
Wide consensus exists that violent conflicts are based on a variety of interconnected causes, of which the environment is considered to be one, but rarely the most decisive factor. Whether the changing climate increases the risk of civil war in Africa remains disputed and little robust research is available to resolve this question. Climate change impacts that intensify competition for increasingly scarce resources like freshwater and arable land, especially in the context of population growth, are areas of concern. The degradation of natural resources as a result of both overexploitation and climate change will contribute to increased conflicts over the distribution of these resources. In addition to these stressors, however, the outbreak of armed conflict depends on many country-specific sociopolitical, economic and cultural factors.

Cross-Chapter Boxes

Box CC-GC. Gender and Climate Change

[Jon Barnett (Australia), Marta G. Rivera Ferre (Spain), Petra Tschakert (U.S.A.), Katharine Vincent (South Africa), Alistair Woodward (New Zealand)]

Gender, along with socio-demographic factors of age, wealth and class, is critical to the ways in which climate change is experienced. There are significant gender dimensions to impacts, adaptation and vulnerability. This issue was raised in WGII AR4 and SREX reports (Adger *et al.*, 2007; IPCC, 2012), but for the AR5 there are significant new findings, based on multiple lines of evidence on how climate change is differentiated by gender, and how climate change contributes to perpetuating existing gender inequalities. This new research has been undertaken in every region of the world (e.g. Brouwer *et al.*, 2007; Nightingale, 2009; Buechler, 2009; Nelson and Stathers, 2009; Dankelman, 2010; MacGregor, 2010; Alston, 2011; Arora-Jonsson, 2011; Resureccion, 2011; Omolo, 2011).

Gender dimensions of vulnerability derive from differential access to the social and environmental resources required for adaptation. In many rural economies and resource-based livelihood systems, it is well established that women have poorer access than men to financial resources, land, education, health and other basic rights. Further drivers of gender inequality stem from social exclusion from decision-making processes and labour markets, making women in particular less able to cope with and adapt to climate change impacts (Rijkers and Costa, 2012; Djoudi and Brockhaus, 2011; Paavola, 2008). These gender inequalities manifest themselves in gendered livelihood impacts and feminisation of responsibilities: whilst both men and women experience increases in productive roles, only women experience increased reproductive roles (Resureccion, 2011; 9.3.5.1.5, Box 13-1). A study in Australia, for example, showed how more regular occurrence of drought has put women under increasing pressure to earn off-farm income, and contribute to more on-farm labor (Alston, 2011). Studies in Tanzania and Malawi demonstrate how women experience food and nutrition insecurity since food is preferentially distributed among other family members (Nelson and Stathers, 2009; Kakota *et al.*, 2011).

AR4 assessed a body of literature that focused on women's relatively higher vulnerability to weather-related disasters in terms of number of deaths (Adger *et al.*, 2007). Additional literature published since that time adds nuances by showing how socially-constructed gender differences affect exposure to extreme events, leading to differential patterns of mortality for both men and women (*high confidence*) [11.3.3, Table 12-3]. Statistical evidence of patterns of male and female mortality from recorded extreme events in 141 countries between 1981-2002 found that disasters kill women at an earlier age than men (Neumayer and Plümper, 2007) [Box 13-1]. Reasons for gendered differences in mortality include various socially- and culturally-determined gender roles. Studies in Bangladesh, for example, show that women do not learn to swim and so are vulnerable when exposed to flooding (Röhr, 2006) and that, in Nicaragua, the construction of gender roles means that middle-class women are expected to stay in the house, even during floods and in risk-prone areas (Bradshaw, 2010). While the differential vulnerability of women to extreme events has long been understood, there is now increasing evidence to show how gender roles for men can affect their vulnerability. In particular, men are often expected to be brave and heroic, and engage in risky life-saving behaviors that increase their likelihood of mortality [Box 13-1]. In Hai Lang district, Vietnam, for example, more men died than women due to their involvement in search and rescue and protection of fields during flooding (Campbell *et al.*, 2009). Women and girls are more likely to become victims of domestic violence after a disaster, particularly when they are living in emergency accommodation, which has been documented in the U.S. and Australia (Jenkins and Phillips, 2008; Anastario *et al.*, 2009; Alston, 2011; Whittenbury, 2013; Box 13-1).

Heat stress exhibits gendered differences, reflecting both physiological and social factors (11.3.3). The majority of studies in European countries show women to be more at risk, but their usually higher physiological vulnerability can be offset in some circumstances by relatively lower social vulnerability (if they are well connected in supportive social networks, for example). During the Paris heat wave, unmarried men were at greater risk than unmarried women, and in Chicago elderly men were at greatest risk, thought to reflect their lack of connectedness in social support networks which led to higher social vulnerability (Kovats and Hajat, 2008). A multi-city study showed geographical variations in the relationship between sex and mortality due to heat stress: in Mexico City, women had a higher risk of mortality than men, although the reverse was true in Santiago and Sao Paulo (Bell *et al.*, 2008).

Recognizing gender differences in vulnerability and adaptation can enable gender-sensitive responses that reduce the vulnerability of women and men (Alston, 2013). Evaluations of adaptation investments demonstrate that those approaches that are not sensitive to gender dimensions and other drivers of social inequalities risk reinforcing existing vulnerabilities (Figueiredo and Perkins, 2012; Arora-Jonsson, 2011; Vincent *et al.*, 2010). Government-supported interventions to improve production through cash-cropping and non-farm enterprises in rural economies, for example, typically advantage men over women since cash generation is seen as a male activity in rural areas (Gladwin *et al.*, 2001;13.3.1). In contrast, rainwater and conservation-based adaptation initiatives may require additional labor which women cannot necessarily afford to provide (Baiphethi *et al.*, 2008). Encouraging gender-equitable access to education and strengthening of social capital are among the best means of improving adaptation of rural women farmers (Below *et al.*, 2012; Goulden *et al.*, 2009; Vincent *et al.*, 2010) and could be used to complement existing initiatives mentioned above that benefit men. Rights-based approaches to development can inform adaptation efforts as they focus on addressing the ways in which institutional practices shape access to resources and control over decision-making processes, including through the social construction of gender and its intersection with other factors that shape inequalities and vulnerabilities (Tschakert, 2013; Bee *et al.*, 2013; Tschakert and Machado, 2012; see also 22.4.3 and Table 22-5).

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Box CC-UP. Uncertain Trends in Major Upwelling Ecosystems

[Salvador E. Lluch-Cota (Mexico), Ove Hoegh-Guldberg (Australia), David Karl (USA), Hans O. Pörtner (Germany), Svein Sundby (Norway), Jean-Pierre Gatusso (France)]

Upwelling is the vertical transport of cold, dense, nutrient-rich, relatively low-pH and often oxygen-poor waters to the euphotic zone where light is abundant. These waters trigger high levels of primary production and a high biomass of benthic and pelagic organisms. The driving forces of upwelling include wind stress and the interaction of ocean currents with bottom topography. Upwelling intensity also depends on water column stratification. The major upwelling systems of the Planet, the Equatorial Upwelling System (EUS, 30.5.2, Figure 30.1A) and the Eastern Boundary Upwelling Ecosystems (EBUE, 30.5.5, Figure 30.1A), represent only 10% of the ocean surface but contribute nearly 25 % to global fish production (Figure 30.1B, Table S30.1).

Marine ecosystems associated with upwelling systems can be influenced by a range of 'bottom-up' trophic mechanisms, with upwelling, transport, and chlorophyll concentrations showing strong seasonal and interannual couplings and variability. These, in turn, influence trophic transfer up the food chain, affecting zooplankton, foraging fish, seabirds and marine mammals.

There is considerable speculation as to how upwelling systems might change in a warming and acidifying ocean. Globally, the heat gain of the surface ocean has increased stratification by 4% (WGI 3.2, 3.4.4, 3.8), which means that more wind energy is needed to bring deep waters to the surface. It is as yet unclear to what extent wind stress can offset the increased stratification, due to the uncertainty in wind speed trends (WGI, 3.4.4). In the tropics, observations of reductions in trade winds over several decades contrast more recent evidence indicating their strengthening since the early 1990s (WGI, 9.4.1.3.4). Observations and modelling efforts in fact show diverging trends in coastal upwelling at the eastern boundaries of the Pacific and the Atlantic. Bakun (1990) proposed that the the difference in heat gaining rates between land and ocean causes an increase in the pressure gradient, which results in increased alongshore winds and leads to intensified offshore transport of surface water through Ekman pumping, and the upwelling of nutrient rich, cold waters (Figure CC-UP). Some regional records support this hypothesis, others do not. There is considerable variability in warming and cooling trends over the past decades both within and among systems making it difficult to predict changes in the intensity of all Eastern Boundary Upwelling Ecosystems (30.5.5).

Understanding whether upwelling and climate change will impact resident biota in an additive, synergistic or antagonistic manner is important for projections of how ecological goods and services provided for human society will change. Even though upwellings may prove more resilient to climate change than other ocean ecosystems because of their ability to function under extremely variable conditions (Capone and Hutchins, 2013), consequences of their shifts are highly relevant since these are the most biologically active systems in the ocean. Increased upwelling would enhance fisheries yields. However, the export of organic material from surface to deeper layers of the ocean may increase and stimulate its decomposition by microbial activity, thereby enhancing oxygen depletion and CO_2 enrichment in deeper water layers. Once this water returns to the surface through upwelling benthic and pelagic coastal communities will be exposed to acidified and deoxygenated water which may combine with anthropogenic impact to negatively affect marine biota and ecosystem structure of the upper ocean (high confidence, 6.3.2, 6.3.3; 30.3.2.2, 30.3.2.3). Extreme hypoxia may result in abnormal mortalities of fishes and invertebrates (Keller *et al.*, 2010), reduce the fisheries catch potential and impact aquaculture in coastal areas (5.4.3.3, 6.3.7, 30.5.1.1.2, 30.5.5.1.3, Barton *et al.*, 2012). Shifts in upwelling also coincide with an apparent increase in the frequency of submarine eruptions of methane and hydrogen sulphide gas, caused by enhanced formation and sinking of phytoplankton biomass to the hypoxic or anoxic sea floor . This combination of factors has been implicated in the extensive mortality of coastal fishes and invertebrates (Bakun and Weeks, 2004), resulting in significant reductions in fishing productivity, such as Cape hake (*Merluccius capensis*), Namibia's most valuable fishery (Hamukuaya *et al.*, 1998).

Reduced upwelling would also reduce the productivity of important pelagic fisheries, such as for sardines, anchovies and mackerel, with major consequences for the economies of several countries (6.4.1, Chp 7, Figure 30.1A, B, Table S30.1). However, under projected scenarios of reduced upward supply of nutrients due to stratification of the open ocean , upwelling of both nutrients and trace elements may become increasingly important to maintaining upper ocean nutrient and trace metal inventories. It has been suggested that upwelling areas may also increase nutrient content and productivity under enhanced stratification, and that upwelled and partially denitrified waters containing excess phosphate may select for N_2-fixing microorganisms (Deutsch *et al*., 2007; Deutsch and Weber, 2012), but field observations of N2 fixation in these regions have not supported these predictions (Fernandez *et al*., 2011; Franz *et al*., 2012). The role of this process in global primary production thus needs to be validated (*low confidence*).

The central question therefore is whether or not upwelling will intensify, and if so, whether the effects of intensified upwelling on O_2 and CO_2 inventories will outweigh its benefits for primary production and associated fisheries and aquaculture (*low confidence*). In any case increasing atmospheric CO_2 concentrations will equilibrate with upwelling waters that may cause them to become more corrosive, depending upon pCO_2 of the upwelled water, and potentially increasingly impact the biota of Eastern Boundary Upwelling Ecosystems.

[INSERT FIGURE UP-1 HERE
Figure UP-1: Upper panel: Schematic hypothetic mechanism of increasing coastal wind-driven upwelling at eastern boundary systems, where differential warming rates between land and ocean results in increased land-ocean pressure gradients (1) that produce stronger alongshore winds (2) and offshore movement of surface water through Ekman transport (3), and increased upwelling of deep cold nutrient rich waters to replace it (4). Lower panel: potential consequences of climate change in upwelling systems. Increasing stratification and uncertainty in wind stress trends result in uncertain trends in upwelling. Increasing upwelling may result in higher input of nutrients to the euphotic zone, and increased primary production, which in turn may enhance pelagic fisheries, but also decreased coastal fisheries due to an augmented exposure of coastal fauna to hypoxic, low pH waters. Decreased upwelling may result in lower primary production in these systems with direct impacts on pelagic fisheries productivity.]

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Box CC-WE: The Water-Energy-Food/Feed/Fiber Nexus as Linked to Climate Change

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Water, energy, and food/feed/fiber are linked through numerous interactive pathways and subject to a changing climate, as depicted in Figure WE-1. The depth and intensity of those linkages vary enormously between countries, regions and production systems. Energy technologies (e.g. biofuels, hydropower, thermal power plants), transportation fuels and modes, and food products (from irrigated crops, in particular animal protein produced by feeding irrigated crops and forages) may require significant amounts of water (Sections 3.7.2, 7.3.2, 10.2, 10.3.4, 22.3.3, 25.7.2; Allan, 2003; King and Weber 2008; McMahon and Price, 2011; Macknick *et al*., 2012a). In irrigated agriculture, climate, irrigating procedure, crop choice and yields determine water requirements per unit of produced crop. In areas where water (and wastewater) must be pumped and/or treated, energy must be provided (Asano et al., 2006; Khan and Hanjra, 2009; USEPA, 2010; Gerten et al., 2011). While food production, refrigeration, transport and processing require large amounts of energy (Pelletier et al., 2011), a major link between food and energy as related to climate change is the competition of bioenergy and food production for land and water (Section 7.3.2, Box 25-10; Diffenbaugh et al., 2012; Skaggs et al., 2012) *(robust evidence, high agreement)*. Food and crop wastes, and wastewater, may be used as sources of energy, saving not only the consumption of conventional non-renewable fuels used in their traditional processes, but also the consumption of the water and energy employed for processing or treatment and disposal (Schievano et al., 2009; Sung et al., 2010; Olson, 2012). Examples of this can be found in several countries across all income ranges. For example, sugar cane by-products are increasingly used to produce electricity or for cogeneration (McKendry, 2002; Kim and Dale 2004) for economic benefits, and increasingly as an option for greenhouse gas mitigation.

[INSERT FIGURE WE-1 HERE
Figure WE-1: The water-energy-food nexus as related to climate change. The interlinkages of supply/demand, quality and quantity of water, energy and food/feed/fiber with changing climatic conditions have implications for both adaptation and mitigation strategies.]

Most energy production methods require significant amounts of water, either directly (e.g., crop-based energy sources and hydropower) or indirectly (e.g., cooling for thermal energy sources or other operations) (Sections 10.2.2 10.3.4, 25.7.4; van Vliet et al., 2012; Davies et al., 2013) *(robust evidence, high agreement).* Water for biofuels, for example, under the IEA Alternative Policy Scenario, which has biofuels production increasing to 71 EJ in 2030, has been reported by Gerbens-Leenes et al. (2012) to drive global consumptive irrigation water use from 0.5% of global renewable water resources in 2005 to 5.5% in 2030, resulting in increased pressure on freshwater resources, with potential negative impacts on freshwater ecosystems. Water is also required for mining (Section 25.7.3), processing, and residue disposal of fossil and nuclear fuels or their byproducts. Water for energy currently ranges from a few percent in most developing countries to more than 50% of freshwater withdrawals in some developed countries, depending on the country (Kenny et al., 2009; WEC, 2010). Future water requirements will depend on electricity demand growth, the portfolio of generation technologies and water management options employed (WEC, 2010; Sattler et al., 2012) *(medium evidence, high agreement)*. Future water availability for energy production will change due to climate change (Sections 3.4, 3.5.1, 3.5.2.2) *(robust evidence, high agreement).*

Water may require significant amounts of energy for lifting, transport and distribution and for its treatment either to use it or to depollute it. Wastewater and even excess rainfall in cities requires energy to be treated or disposed. Some non-conventional water sources (wastewater or seawater) are often highly energy intensive. Energy intensities per m^3 of water vary by about a factor of 10 between different sources, e.g. locally produced potable water from ground/surface water sources vs. desalinated seawater (Box 25-2, Tables 25-6 and 25-7; Macknick et al., 2012b; Plappally and Lienhard, 2012). Groundwater (35% of total global water withdrawals, with irrigated food production being the largest user; Döll et al., 2012) is generally more energy intensive than surface water. In India, for example, 19% of total electricity use in 2012 was for agricultural purposes (Central Statistics Office, 2013), with a large share for groundwater pumping. Pumping from greater depth increases energy demand significantly– electricity use ($kWhr/m^3$ of water) increases by a factor of 3 when going from 35 to 120 m depth (Plappally and Lienhard, 2012). The reuse of appropriate wastewater for irrigation (reclaiming both water and energy-intense nutrients) may increase agricultural yields, save energy, and prevent soil erosion (Smit and Nasr, 1992; Jimenez, 1996; Wichelns et al., 2007; Raschid-Sally and Jayakody, 2008) *(medium confidence)*. More energy efficient treatment methods enable poor quality (“black”) wastewater to be treated to quality levels suitable for discharge into water courses, avoiding additional fresh water and associated energy demands (Keraita et al, 2008). If properly treated to retain nutrients, such treated water may increase soil productivity, contributing to increased crop yields/food security in regions unable to afford high power bills or expensive fertilizer (Oron, 1996; Lazarova and Bahri, 2005; Redwood and Huibers, 2008; Jimenez, 2009) *(high confidence)*.

Linkages among water, energy, food/feed/fiber and climate are also strongly related to land use and management (Section 4.4.4, Box 25-10) *(robust evidence, high agreement)*. Land degradation often reduces efficiency of water and energy use (e.g. resulting in higher fertilizer demand and surface runoff), and compromises food security (Sections 3.7.2, 4.4.4). On the other hand, afforestation activities to sequester carbon have important co-benefits of reducing soil erosion and providing additional (even if only temporary) habitat (see Box 25-10) but may reduce renewable water resources. Water abstraction for energy, food or biofuel production or carbon sequestration can also compete with minimal environmental flows needed to maintain riverine habitats and wetlands, implying a potential conflict between economic and other valuations and uses of water (Sections 25.4.3 and 25.6.2, Box 25-10) *(medium evidence, high agreement)*. Only a few reports have begun to evaluate the multiple interactions among energy, food, land, and water and climate (McCornick et al., 2008; Bazilian et al., 2011; Bierbaum and Matson, 2013), addressing the issues from a security standpoint and describing early integrated modeling approaches. The interaction among each of these factors is influenced by the changing climate, which in turn impacts energy and water demand, bioproductivity and other factors (see Figure WE-1 and Wise et al., 2009), and has implications for security of supplies of energy, food and water, adaptation and mitigation pathways, air pollution reduction as well as the implications for health and economic impacts as described throughout this report.

The interconnectivity of food/fiber, water, land use, energy and climate change, including the perhaps not yet well understood cross-sector impacts, are increasingly important in assessing the implications for adaptation/mitigation policy decisions. Fuel-food-land use-water-GHG mitigation strategy interactions, particularly related to bioresources for food/feed, power, or fuel, suggest that combined assessment of water, land type and use requirements, energy requirements and potential uses and GHG impacts often epitomize the interlinkages. For example, mitigation scenarios described in the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (IPCC, 2011) indicate up to 300EJ of biomass primary energy by 2050 under increasingly stringent mitigation scenarios. Such high levels of biomass production, in the absence of technology and process/management/operations change, would have significant implications for land use, water and energy, as well as food production and pricing. Consideration of the interlinkages of energy, food/feed/fiber, water, land use and climate change is increasingly recognized as critical to effective climate resilient pathway decision making *(medium evidence, high agreement)*, although tools to support local- and regional-scale assessments and decision-support remain very limited.

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Table 22-1: Major conclusions from previous IPCC assessments.

Report	Major conclusions	Reference
IPCC special report on regional climate change	• Sensitivity of **water resources and coastal zones** to climatic parameters • Identification of climate change as an **additional burden** on an already stressful situation • **Major challenges for Africa**: Lack of data on energy sources; uncertainties linked to climate change scenarios (mainly for precipitation); need for integrated studies; and the necessary links between science and decision makers	Zinyowera *et al.*, 1997
Third Assessment Report (TAR)	• **Impacts of climate change on and vulnerability of six sectors**: water resources; food security; natural resources and biodiversity management; health; human settlements and infrastructure; desertification • **Adaptation strategies** for each of the sectors • Threats of **desertification** and **droughts** to the economy of the continent • **Suggestion of adaptation options**: mainly linked with better resource management • **Identification of research gaps and needs**: capacity building; data needs; development of integrated analysis; consideration of literature in other languages	Desanker *et al.*, 2001
Fourth Assessment Report (AR4)	• Vulnerability of Africa mainly due to its **low adaptive capacity** • **Sources of vulnerability** mainly socioeconomic causes (demographic growth, governance, conflicts, etc.) • **Impacts of climate change on various sectors**: energy, tourism and coastal zones considered separately • Potential impacts of extreme weather events (droughts and floods) • Adaptation costs • Need for mainstreaming climate change adaptation into national development policies • Two case studies: ***1.*** Food security: climate change could affect the three main components of food security ***2.*** Traditional Knowledge: African communities have prior experience with climate variability, although this knowledge will not be sufficient to face climate change impacts. • **Research needs**: better knowledge of climate variability; more studies on the impacts of climate change on water resources, energy, biodiversity, tourism, and health; the links between different sectors (e.g., between agriculture, land availability, and biofuels); developing links with the disaster reduction community; increasing interdisciplinary analysis of climate change; and strengthening institutional capacities	Boko *et al.*, 2007

Table 22-2: Under-nourishment in Africa, by number and % of total population.

Undernourished	1990 – 1992	1999 – 2001	2004 – 2006	2007 – 2009	2010 – 2012
Million	175	205	210	220	239
(%) of total population	27.3%	25.3%	23.1%	22.6%	22.9%

Source: IFAD *et al.*, 2012

Table 22-3: Examples of detected changes in species, natural ecosystems, and managed ecosystems in Africa that are both consistent with a climate change signal and published since the AR4. Confidence in detection of change is based on the length of study, and the type, amount and quality of data in relation to the natural variability in the particular species or system. Confidence in the role of climate being a major driver of the change is based on the extent to which the detected change is consistent with that expected under climate change, and to which other confounding or interacting non-climate factors have been considered and been found insufficient to explain the observed change.

Type of change and nature of evidence	**Examples**	**Time scale of observations**	**Confidence in the detection of change**	**Potential climate change driver(s)**	**Confidence in the role of climate vs. other drivers**
Changes in ecosystem types *Robust evidence*	Across sub-Saharan Africa, 57% increase in agricultural areas and 15% increase in barren (largely desert) areas was accompanied by 16% decrease in total forest cover and 5% decrease in total non-forest cover (Brink and Eva, 2009)	~ 25 years (1975-2000)	**medium**	Increasing CO_2, changing precipitation patterns, increasing temperatures	**low**
	On Mt. Kilimanjaro, increased vulnerability to anthropogenic fires has driven 9% decreases in montane forest and 83% decreases in subalpine forest (Hemp, 2009)	~ 25 years (1976-2000)	**high**	Increasing temperatures, decreasing precipitation	**Low**
	In the Democratic Republic of the Congo, total forest cover declined by 2.3%, with most losses in secondary humid forest (Potapov *et al*., 2012)	~ 10 years (2000-2010)	**high**	None proposed	**low**
	Dieback of seaward edge of mangroves in Cameroon at rates up to 3 m $year^{-1}$ (Ellison and Zhou, 2012)	~ 35 years (1975-2010)	**high**	Sea level rise	**medium**
	Across western Africa, central Africa and Madagascar, net deforestation was 0.28% $year^{-1}$ for 1990-2000 and 0.14% $year^{-1}$ for 2000-2010 (Mayaux *et al*., 2013)	~ 20 years (1990-2010)	**high**	None proposed	**low**

Changes in ecosystem structure *Robust evidence*	Surveys of coral reefs in northern Tanzania indicate relative stability in the abundance and diversity of species, despite climate and non-climate stressors (McClanahan *et al*., 2009)	~ 9 years (1996-2005)	**high**	None proposed	**low**
	Analysis of sediment cores from Lake Victoria indicates current community structure (i.e., dominated by cyanobacteria and invasive fish) was established rapidly, during the 1980s (Hecky *et al*., 2010)	~ 100 years (1900-2000)	**high**	Increasing temperatures	**Low**
	Long-term declines in density of trees and shrubs in the Sahel zone of Senegal (Vincke *et al*., 2010) and Mali (Ruelland *et al*., 2011)	~ 20-50 years (Senegal, 1976-1995; Mali, 1952-2003)	**high**	Drought stress induced by decreasing precipitation	**low**
	Southward shift in the Sahel, Sudan, and Guinean savanna vegetation zones inferred from declines in tree density in Senegal and declines in tree species richness and changes in species composition in Mauritania, Mali, Burkina Faso, Niger, and Chad (Gonzales *et al*., 2012)	~ 40-50 years (density,1954-2002; diversity, 1960-2000)	**medium**	Increasing temperatures, decreasing precipitation	**medium**
	Long-term increase in shrub and tree cover across mesic savanna sites (700-1000 mm MAP) with contrasting land-use histories in South Africa (Wigley *et al*., 2009; Wigley *et al*., 2010)	~67 years (1937-2004)	**high**	Increasing CO_2	**low**
	In long-term field experiments in South Africa where disturbance from fire and herbivory was controlled, density of trees and shrubs increased in mesic savannas (600 and 750 mm MAP) but showed no change in a semi-arid savanna (550 mm MAP) (Buitenwerf *et al*., 2012)	~ 30 – 50 years (1980-2010 for 600 mm MAP site; 1954-2004 for 550 & 750 mm MAP sites)	**high**	In mesic site, increasing CO_2; but lack of response in semiarid site surprising and unexplained	**Medium**
Changes in ecosystem physiology *Moderate evidence*	A reconstruction of drought history in Tunisia and Algeria based on tree ring records from *Cedrus atlantica* and *Pinus halepensis* indicates that a 1999-2002 drought was the most severe since the 15th century (Touchan *et al*., 2008)	~ 550 years (1456–2002)	**high**	Increasing temperatures, decreasing precipitation	**low**
	Across 79 African tropical forest plots, above-ground carbon storage in live trees increased by 0.63 Mg C ha^{-1} yr^{-1} (Lewis *et al*., 2009)	~ 40 years (1968-2007)	**high**	Increasing CO_2	**Medium**
	Increased stratification and reduced nutrient fluxes and primary productivity in Lake Tanganyika (Verburg and Hecky, 2009)	~ 90 years (1913-2000)	**high**	Increasing temperatures	**High**
	Recent increases in surface temperatures and decreases in productivity of Lake Tanganyika exceed the range of natural variability (Tierney *et al*., 2010)	~ 1,500 years (500-2000)	**high**	Increasing temperatures	**High**

Changes in species distributions, physiology, or behavior *Moderate evidence*	The range of *Aloe dichotoma*, a Namib Desert tree, is shifting poleward, but extinction along trailing edge exceeds colonization along leading edge (Foden *et al*., 2007)	~ 100 years (1904-2002)	**high**	Increasing temperatures, decreasing precipitation	**Medium**
	On Tsaratanana Massif, the highest mountain in Madagascar, reptiles and amphibians are moving upslope (Raxworthy *et al*., 2008)	~ 10 years (1993-2003)	**high**	Increasing temperatures	**Medium**
	Pomacentrus damselfish species vary in avoidance of predation-related mortality under elevated CO_2 (Ferrari *et al*., 2011)	minutes to days (Nov.-Dec. 2009)	**high**	Increasing CO_2	**low**
	In greenhouse experiments, growth of seedlings of woody savanna species (*Acacia karoo* and *Terminalia sericea*) was enhanced at elevated CO_2 (Bond and Midgley, 2012)	~1-2 years	**high**	Increasing CO_2	**medium**

Table 22-4: Projected changes in agro-climatic suitability for perennial crops in Africa by mid-century under an A2 scenario.

Crop	**Suitability change**	**Country**	**Source**
Coffee	Increased suitability at high latitudes; decreased suitability at low latitudes	Kenya	Läderach et al., 2010
Tea	Decreased suitability	Uganda	Eitzinger et al., 2011a,b
	Increased suitability at high latitudes; decreased suitability at low latitudes	Kenya	
Cocoa	Constant or increased suitability at high latitudes; decreased suitability at low latitudes	Ghana, Côte d'Ivoire	Läderach et al., 2011c
Cashew	Increased suitability	Ghana, Côte d'Ivoire	Läderach et al., 2011a
Cotton	Decreased suitability	Ghana, Côte d'Ivoire	Läderach et al., 2011b

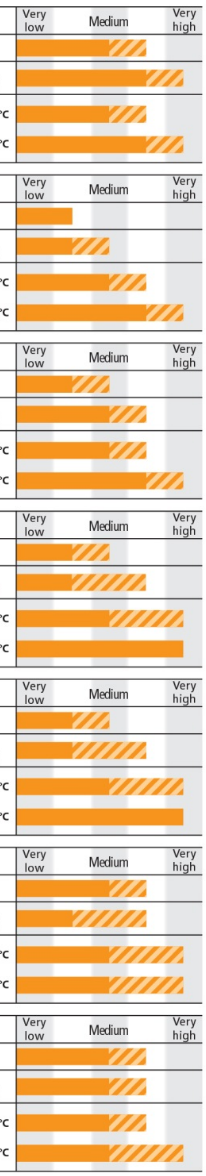
Table 22-5: Cross-cutting approaches for equity and social justice in adaptation.

Equitable adaptation approach	**Key issues to address for adaptation**	**Factors that could cause maladaptation**	**Opportunities**	**Lessons learned**
Gender mainstreamed adaptation in Africa	Lack of empowerment and participation in decision-making (Patt *et al*., 2009) Climate impacts increase women's household roles, with risk of girls missing school to assist (Raworth, 2008; Romero González *et al.*, 2011; UNDP, 2011b) Male adaptation strategies e.g. migration risk increasing women's vulnerability (Djoudi and Brockhaus, 2011)	Employment opportunities not sufficiently extended to women in adaptation initiatives (Madzwamuse, 2010) Failure to incorporate power relations in adaptation responses (Djoudi and Brockhaus, 2011; Romero González *et al.*, 2011)	Women's aptitude for long-term thinking, trusting and integrating scientific knowledge, and taking decisions under uncertainty (Patt *et al.*, 2009) Potential long-term increase in women's empowerment and social and economic status (Djoudi and Brockhaus, 2011) Women opportunistically using development projects for adaptation (Nielsen, 2010)	Security of tenure over land and resource access is critical for enabling enhanced adaptive capacity of women (ADF, 2010) Research on understanding different adaptive strategies of benefit for women and men is needed
Child-centered approaches to adaptation	Children and youth represent over 60% of Africa's population, yet their issues are largely absent from adaptation policy (ADF, 2010) Children's differential vulnerability to projected climate impacts is high, particularly to hunger, malnutrition and disasters (UNICEF, 2007)	Limits to children's agency related to power imbalances between children and adults, and different cultural contexts (Seballos *et al*., 2011)	Using approaches that stress agency and empowerment, and 'innovative energies' of youth; build on targeted adaptation initiatives, such as child-centred disaster risk reduction and adaptation (ADF, 2010; Seballos *et al.*, 2011)	Positive role of children and youth as change agents for climate adaptation, within appropriate enabling environment Child-sensitive programmes and policies can reduce risks children face from disasters (Seballos et al, 2011) Funding for climate resilience programmes will protect children's basic rights (UNICEF, 2010; UNICEF, 2011)
Human rights-based approaches (HRBA)	Common critical rights issues for local communities are land/resource rights, gender equality, and political voice and fair adjudication of grievances for the poor and excluded (Castro *et al.*, 2012)	Lack of recognition and promotion of their human rights blocks indigenous peoples' coping and adaptation capacities (UNPFII, 2008)	Using the HRBA lens to understand climate risk necessitates risk analysis to probe the root causes of differential disaster risk vulnerabilities, to enable structural, sustainable responses (Urquhart, 2014)	Applying HRBA presents a framework for addressing conflicting rights and interests, necessary for building resilience and equitable adaptation responses (Nilsson and Schnell, 2010)

Table 22-6: Key risks from climate change and the potential for risk reduction through mitigation and adaptation in Africa. Key risks are identified based on assessment of the literature and expert judgments made by authors of the various WGII AR5 chapters, with supporting evaluation of evidence and agreement in the referenced chapter sections. Each key risk is characterized as very low, low, medium, high, or very high. Risk levels are presented for the near-term era of committed climate change (here, for 2030-2040), in which projected levels of global mean temperature increase do not diverge substantially across emissions scenarios. Risk levels are also presented for the longer-term era of climate options (here, for 2080-2100), for global mean temperature increase of 2°C and 4°C above preindustrial levels. For each timeframe, risk levels are estimated for the current state of adaptation and for a hypothetical highly adapted state. As the assessment considers potential impacts on different physical, biological, and human systems, risk levels should not necessarily be used to evaluate relative risk across key risks. Relevant climate variables are indicated by symbols.

Key risk	Adaptation issues and prospects	Climatic drivers	Supporting ch. sections	Timeframe
Shifts in biome distribution, and severe impacts on wildlife due to diseases and species extinction (*high confidence*)	Very few adaptation options; migration corridors; protected areas; better management of natural resources	Warming trend; Sea level; Precipitation; Sea surface temperature	22.3.2.1, 22.3.2.3	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C
Stress on water resources currently facing significant strain from overexploitation and degradation, and increased future demand, will be compounded by temperature rise and changes in precipitation (*high confidence*)	Reducing nonclimate stressors on water resources is critical for realizing adaptation co-benefits. Strengthening institutional capacities for demand management, groundwater assessment, integrated water-wastewater planning and integrated land and water governance would advance adaptation planning.	Warming trend; Precipitation; Extreme temperature; Extreme precipitation; Sea level	22.3.2.2, 22.3.3, 22.4.2, 22.4.4, 22.4.5	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C
Degradation of coral reefs results in loss of protective ecosystems and fishery stocks (*medium confidence*)	Few adaptation options; marine protected areas; conservation and protection; better management of natural resources.	Ocean acidification; Sea level; Damaging cyclone; Sea surface temperature	22.3.2.3	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C
Reduced crop productivity with strong adverse effects on regional, national and household food security, linked to temperature rise and precipitation changes, and secondary (indirect) impacts, such as those linked to increased pest and disease damage and flood risks to food system infrastructure (*high confidence*)	Adaptation can be made more effective where technologic adaptation responses (e.g. stress tolerant crop varieties, irrigation, etc.) are embedded within efforts to enhance smallholder access to credit and other critical production resources, livelihoods diversification, institutional strengthening at local to regional levels to support agriculture and strong gender oriented policy support.	Warming trend; Precipitation; Extreme temperature; Extreme precipitation	22.3.4.1, 22.4.5.2, 22.4.5.4, 22.4.5.6, 22.4.5.7, 22.4.6	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C
Adverse effects on livestock linked to temperature rise and precipitation changes that lead to increased heat and water stress, and shifts in the range of pests and diseases, with adverse impacts on pastoral livelihoods and rural poverty (*medium confidence*)	Addressing nonclimate stressors facing pastoralists, including policy and governance features that perpetuate their marginalization, is critical for reducing vulnerability. Natural resource-based strategies such as reducing drought risk to pastoral livelihoods through use of forest goods and services hold potential, provided sufficient attention is paid to forest conservation and sustainable management.	Warming trend; Precipitation; Extreme temperature; Extreme precipitation	22.3.4.2, 22.4.5.2, 22.4.5.6, 22.4.5.8	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C
Changes in the incidence and geographic range of vector- and water-borne diseases due to changes in the mean and variability of temperature and precipitation, particularly along the edges of their distribution (*medium confidence*)	Achieving development goals, particularly improvement in access to safe water and improved sanitation, along with enhancement of public health functions, such as surveillance. Specific adaptation options include vulnerability mapping and early warning systems. Coordination activities with other sectors.	Warming trend; Precipitation; Extreme precipitation	22.3.5, 22.3.5.2	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C
Undernutrition, with its potential for life-long impacts on health and development and its associated increase in vulnerability to malaria and diarrheal diseases, can result from changing crop yields, migration due to weather and climate extremes, and other factors (*medium confidence*)	Early warning systems and vulnerability mapping (for targeted interventions); diet diversification; coordination with food and Agriculture sectors; improved public health functions to address underlying diseases.	Warming trend; Precipitation; Extreme temperature; Extreme precipitation	22.3.5.2	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C

Risk for current and high adaptation:



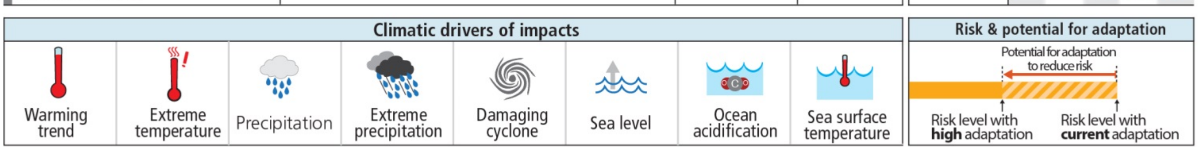


Table 22-7: Land inundated and economic impacts in Cape Town based on a risk assessment (Cartwright, 2008).

Sea level rise scenarios	**Land inundated**	**Economic impacts (for 25 years)**
Scenario 1 (+ 2.5 to 6.5 m depending on the exposure) 95%	25.1 km^2 (1% of the total CT area)	5.2 billion R (794 million US$)
Scenario 2 (+ 4.5 m) 85%	60.9 km^2 (2% of the total CT area)	23.7 billion R (30.3 billion US$)
Scenario 3 (+6.5 m) 20%	95 km^2 (4% of the total CT area)	54.8 billion R

Note: The economic impacts are determined based on the value of properties, losses of touristic revenues and the cost of infrastructure replacement. The total geographical gross product for Cape Town in 2008 was 165 billion of Rands.

Table 22-8: Research gaps in different sectors.

Key Sectors	**Gaps observed**
Climate Science	•Research in climate and climate impacts would be greatly enhanced if data custodians and researchers worked together to use observed station data in scientific studies. Research into regional climate change and climate impacts relies on observed climate and hydrological data as an evaluative base. These data are most often recorded by meteorological institutions in each country and sold to support data collection efforts. However, African researchers are generally excluded from access to these critical data due to the high costs involved which hinders both climate and climate impacts research. •Downscaling GCM data to the regional scale captures the influence of topography on the regional climate. Regional climate information is essential for understanding regional climate processes, regional impacts and potential future changes in these. Additionally, impacts models such as hydrology and crop models generally require input data at a resolution higher than what GCMs can provide. Regional downscaling, either statistically or through using regional climate models, can provide information at these scales and can also change the sign of GCM-projected rainfall change over topographically complex areas [22.2.2.2].
Ecosystems	•Monitoring networks for assessing long-term changes to critical ecosystems such as coastal ecosystems, lakes, mountains, grasslands, forests, wetlands, deserts, and savannas to enhance understanding of long-term ecological dynamics, feedbacks between climate and ecosystems, the effects of natural climate variability on ecosystems, the limits of natural climate variability, and the marginal additional effects of global climate forcing. •Develop the status of protected areas to include climate change effects
Food Systems	•Socioeconomic and environmental tradeoffs of biofuel production, especially the effect on land use change and food and livelihood security; better agronomic characterization of biofuel crops to avoid maladaptive decisions with respect to biofuel production •Vulnerability to and impacts of climate change on food systems (production, transport, processing, storage, marketing and consumption) •Impacts of climate change on urban food security, and dynamic of rural-urban linkages in vulnerability and adaptive capacity •Impacts of climate change on food safety and quality
Water resources	•Characterization of Africa's groundwater resource potential; understanding interactions between non-climate and climate drivers as related to future groundwater resources. •Impacts of climate change on water quality, and how this links to food and health security •Decision making under uncertainty with respect to water resources given limitations of climate models for adequately capturing future rainfall projections

Human security and urban areas	•Research to explore and monitor the links between climate change and migration and its potential negative effects on environmental degradation; the potential positive role of migration in climate change adaptation. •Improved methods and research to analyse the relation between climate change and violent conflict.
Livelihoods and poverty	•Methodologies for cyclical learning and decision-support to enable anticipatory adaptation in contexts of high poverty and vulnerability (Tschakert and Dietrich, 2010) •Frameworks to integrate differentiated views of poverty into adaptation and disaster risk reduction, and to better link these with social protection in different contexts •Ethical and political dimensions of engaging with local and traditional knowledge on climate change
Health	Research and improved methodologies (including longitudinal studies) to assess and quantify the impact of climate change on vector borne, foodborne, waterborne, nutrition, heatstress and indirect impacts on HIV. Research to quantify the direct and indirect health impacts of extreme weather events in Africa; injuries, mental illness; health infrastructure Frameworks and research platforms to be developed with other sectors to determine how underlying risks (for example food security) will be addressed to improve health outcomes.
Adaptation	Research to develop home-grown and to localize global adaptation technologies to build resilience Equitable adaptation frameworks to deal with high uncertainty levels and integrate marginalized groups; and that identify and eliminate multi-level constraints to women's adaptive ability Multi--tiered approach to building institutional and community capacity to respond to climate risk Potential changes in economic and social systems under different climate scenarios, to understand the implications of adaptation and planning choices (Clements *et al.*, 2011) Principles/determining factors for effective adaptation, including community-based adaptation Understanding synergies and trade-offs between different adaptation and mitigation approaches (Chambwera and Anderson, 2011) Additional national and sub-natinal modeling and analysis of the economic costs of impacts and adaptation, including of the 'soft' costs of impacts and adaptation Monitoring adaptation
Other	Methods in vulnerability analysis for capturing the complex interactions in systems across scales Understanding compound impacts from concomitant temperature and precipitation stress, e.g. effect on a particular threshold of a heatwave occurring during a period of below normal precipitation.

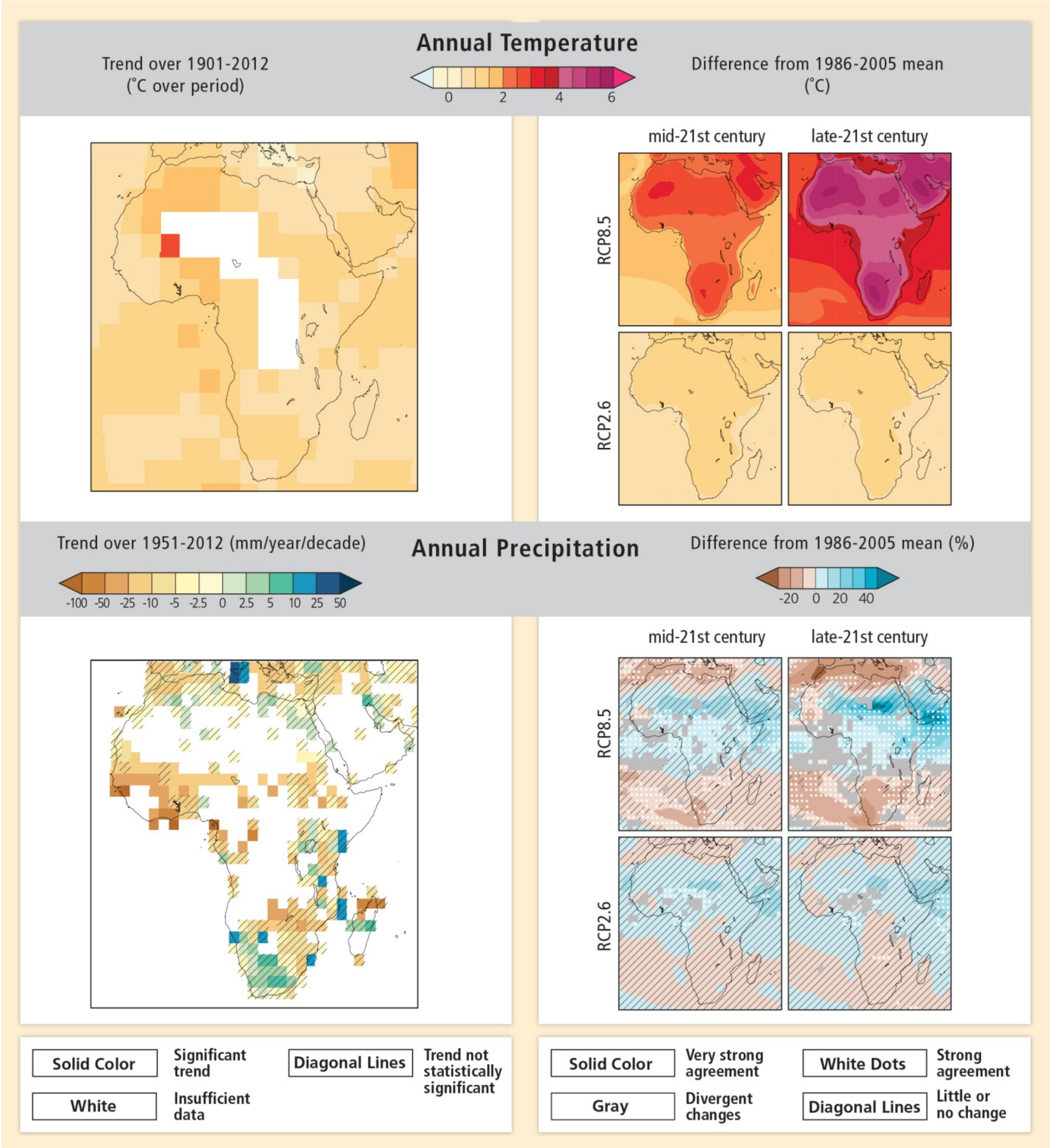
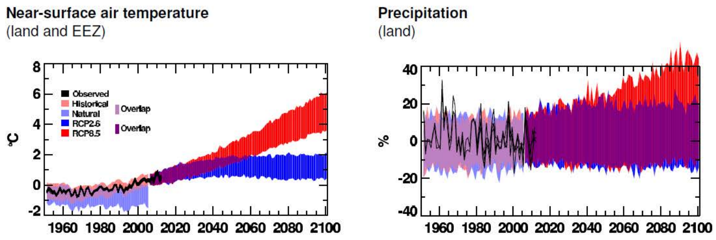
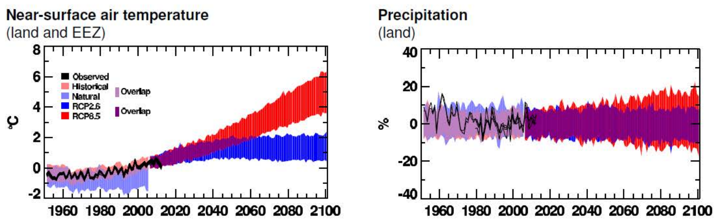


Figure 22-1: Observed and simulated variations in past and projected future annual average precipitation and temperature. Observed differences in the Climate Research Unit, University of East Anglia data (CRU) are shown between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For CMIP5, white indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Grey indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st Century period is 2081-2100. The mid-21st century period is 2046-2065.

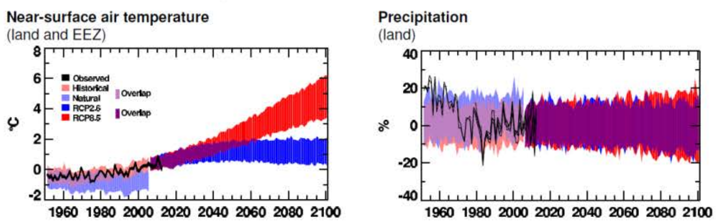
The East African Community, the Intergovernmental Authority on Development, and Egypt



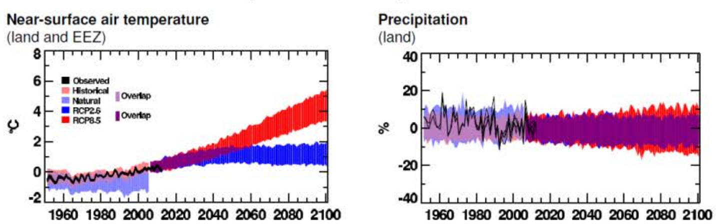
The Economic Community of Central African States



The Economic Community Of West African States



The Southern African Development Community



The Arab Magreb Union

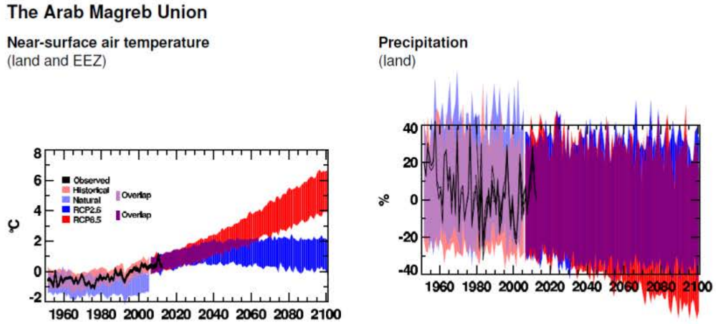


Figure 22-2: Observed and simulated variations in past and projected future annual average temperature over EAC-IGAD-Egypt, ECCAS, ECOWAS, SADC and UMA. Black lines show various estimates from observational measurements. Shading denotes the 5-95 percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (63 simulations), historical changes in "natural" drivers only (34), the "RCP2.6" emissions scenario (63), and the "RCP8.5" (63). Data are anomalies from the 1986-2005 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Box 21-3.
[Illustration to be redrawn to conform to IPCC publication specifications.]

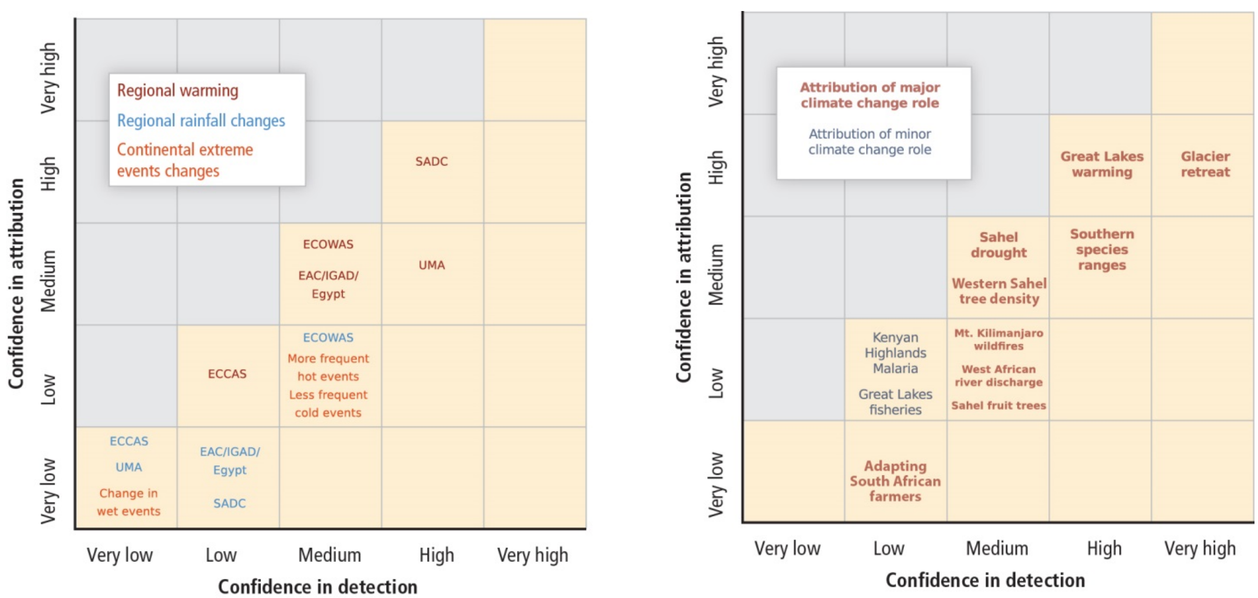


Figure 22-3: Left: Confidence in detection and in attribution of observed climate change over Africa to anthropogenic emissions. All detection assessments are against a reference of no change, while all attribution assessments concern a major role of anthropogenic emissions in the observed changes. See 22.2, and SREX-3, and WGI AR5 10 for details. Right: Confidence in detection and in attribution of the impacts of observed regional climate change on various African systems. All detection assessments are against a reference of no change, except "Kenyan Highlands malaria" (changes due to vaccination, drug resistance, demography, and livelihoods), "Great Lakes fisheries" (changes due to fisheries management and land use) and “Adapting South African farmers” (economic changes). Attribution is to a major role or a minor role of observed climate change, as indicated. See 22.2.2, 22.3.2.1, 22.3.2.2, 2.3.3, 22.4.2, 22.3.4.4, 22.3.5.4, 22.4.5.7 and Tables 18-5, 18-6, 18-7, and 18-9 for details. Assessments follow the methods outlined in 18.2.

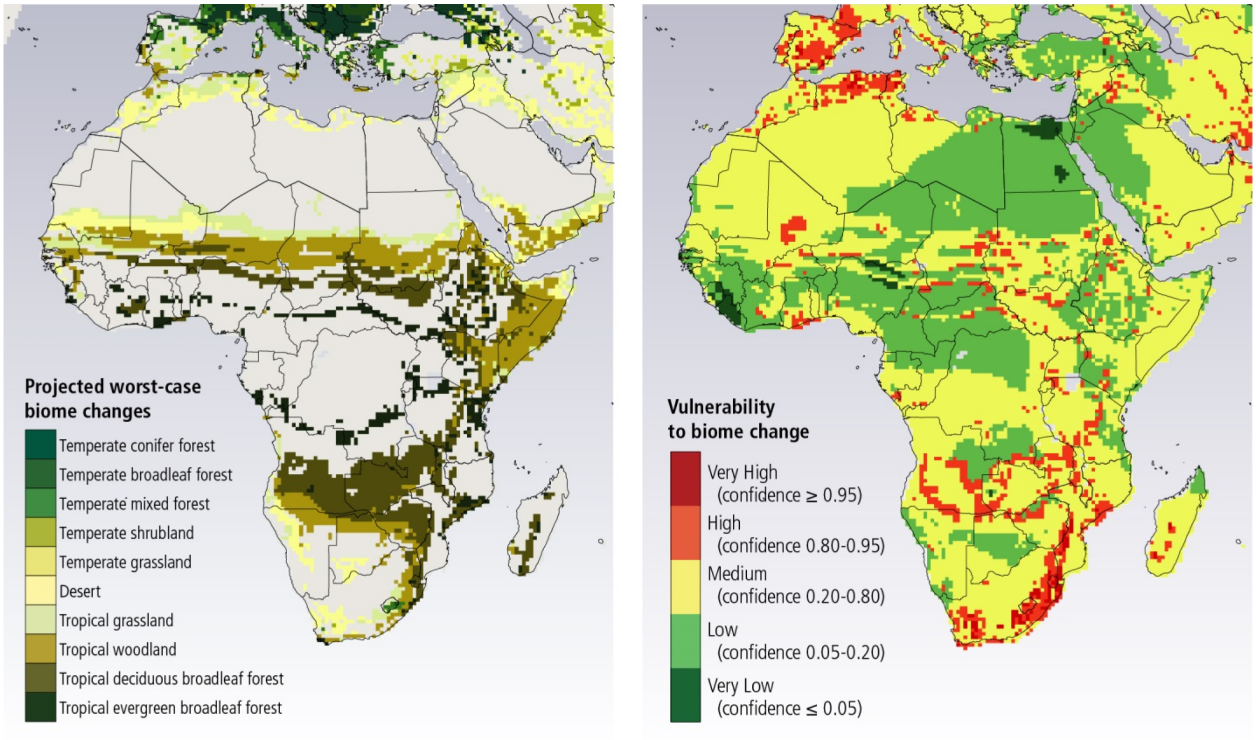


Figure 22-4: Left – Projected biome change from the periods 1961-1990 to 2071-2100 using the MC1 Dynamic Vegetation Model. Change is indicated if any of nine combinations of three GCMs (CSIRO Mk3, HadCM3, MIROC 3.2 medres) and three emissions scenarios (B1, A1B, A2) project change and is thus a worst-case scenario. Colours represent the future biome predicted. Right – Vulnerability of ecosystems to biome shifts based on historical climate (1901-2002) and projected vegetation (2071-2100), where all nine GCM-emissions scenario combinations agree on the projected biome change. Source: Gonzalez et al. (2010).

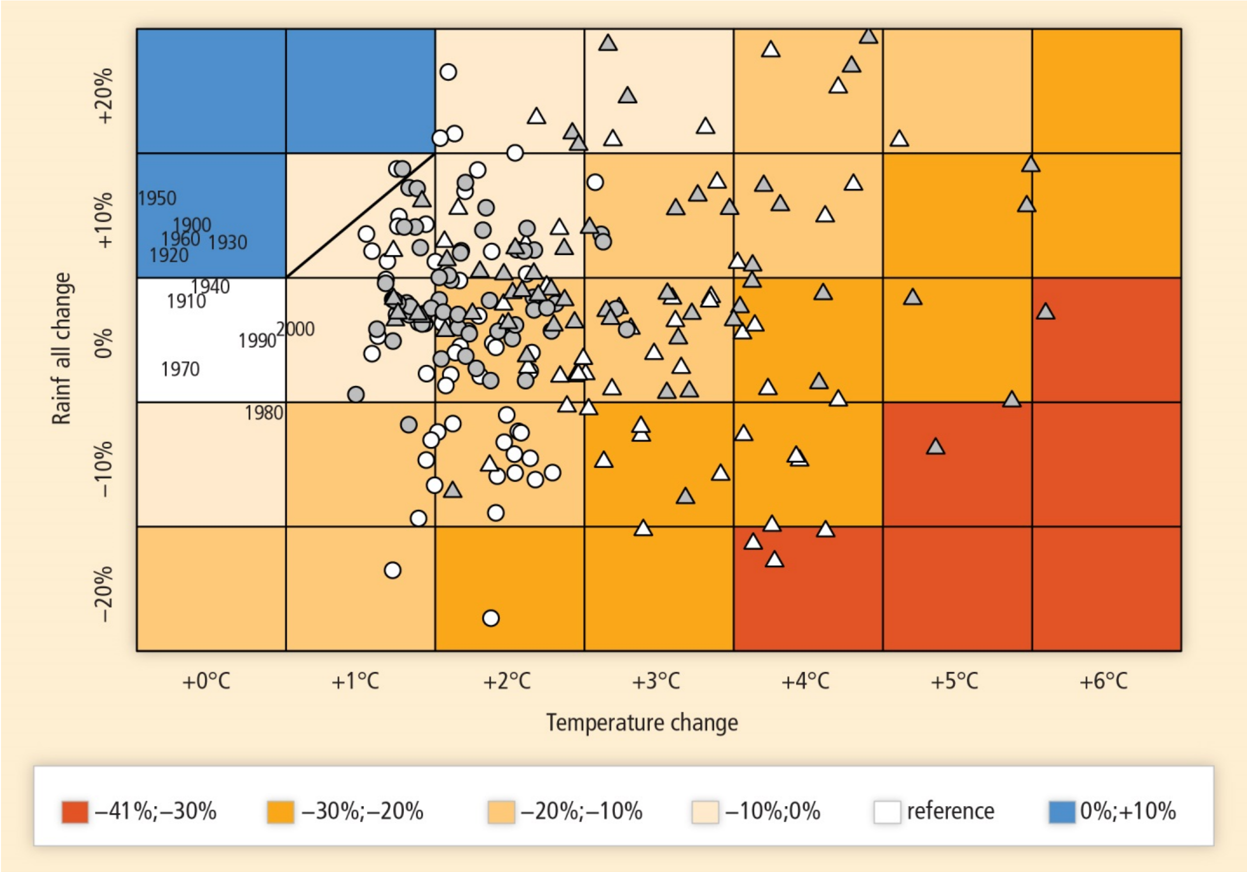


Figure 22-5: The effect of rainfall and temperature changes on mean crop yield. Mean crop yield change (%) relative to the 1961–90 baseline for 7 temperatures (x-axis) and 5 rainfall (y-axis) scenarios. Results are shown as the average over the 35 stations across West Africa and the 6 cultivars of sorghum and millet. White triangles and circles are the projected anomalies computed by several CMIP3 GCMs and three IPCC emission scenarios (B1, A1B, A2) for 2071–90 and 2031–50, respectively. Projections from CMIP5 GCMs and three RCPs (4.5, 6.0 and 8.5) are represented by grey triangles and circles. Models and scenarios names are displayed in figure S2 (available at stacks.iop.org/ERL/8/014040/mmedia). Past observed climate anomalies from CRU data are also projected by computing 10-year averages (e.g. '1940' is for 1941–50). All mean yield changes are significant at a 5% level except boxes with a diagonal line. Source: Sultan et al., 2013.

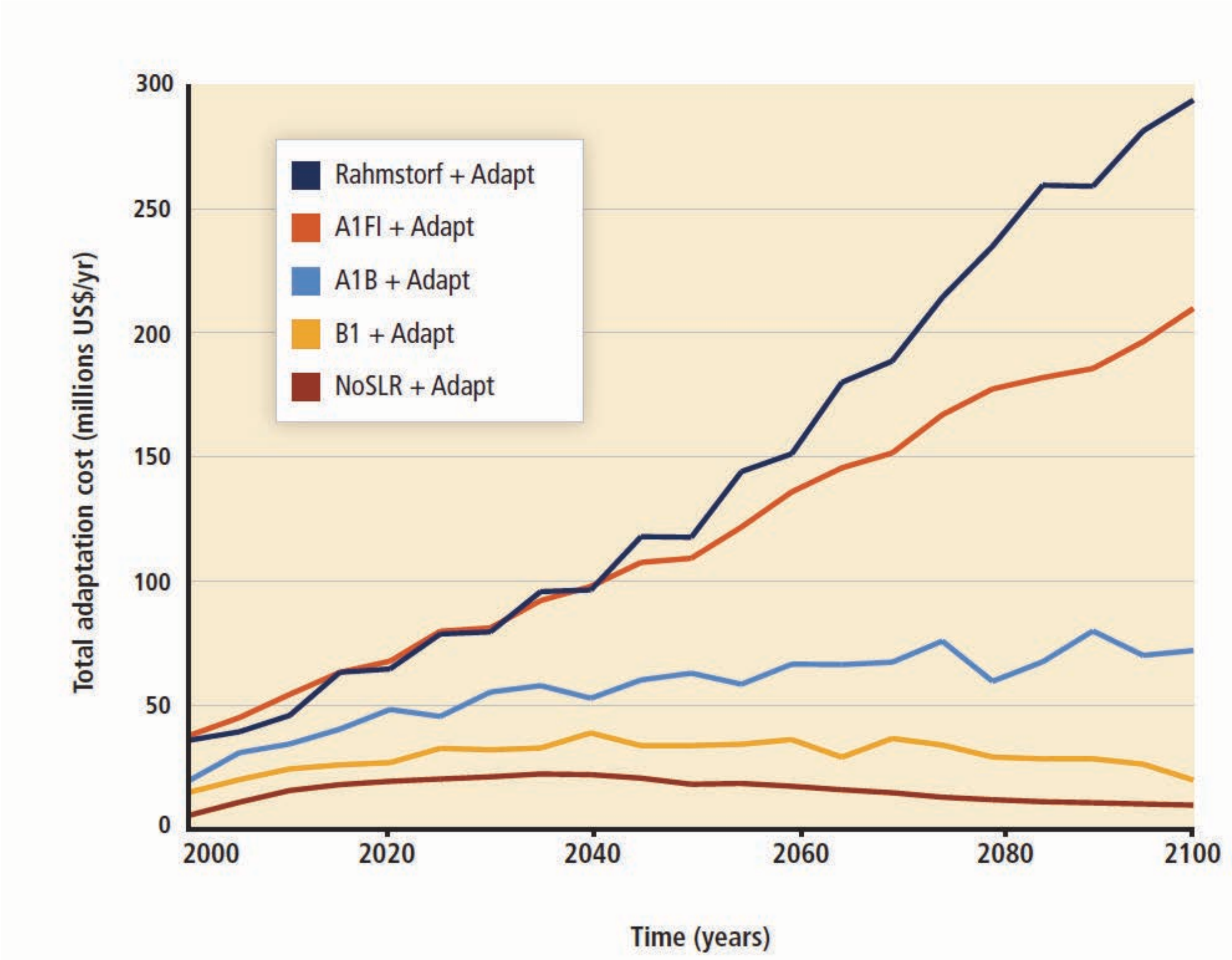


Figure 22-6: Total additional costs of adaptation per year from 2000 to 2100 for Tanzania (including beach nourishment and sea and river dikes). The values do not consider the existing adaptation deficit (values in $US2005), without discounting. Source: Kebede *et al.*, 2010.

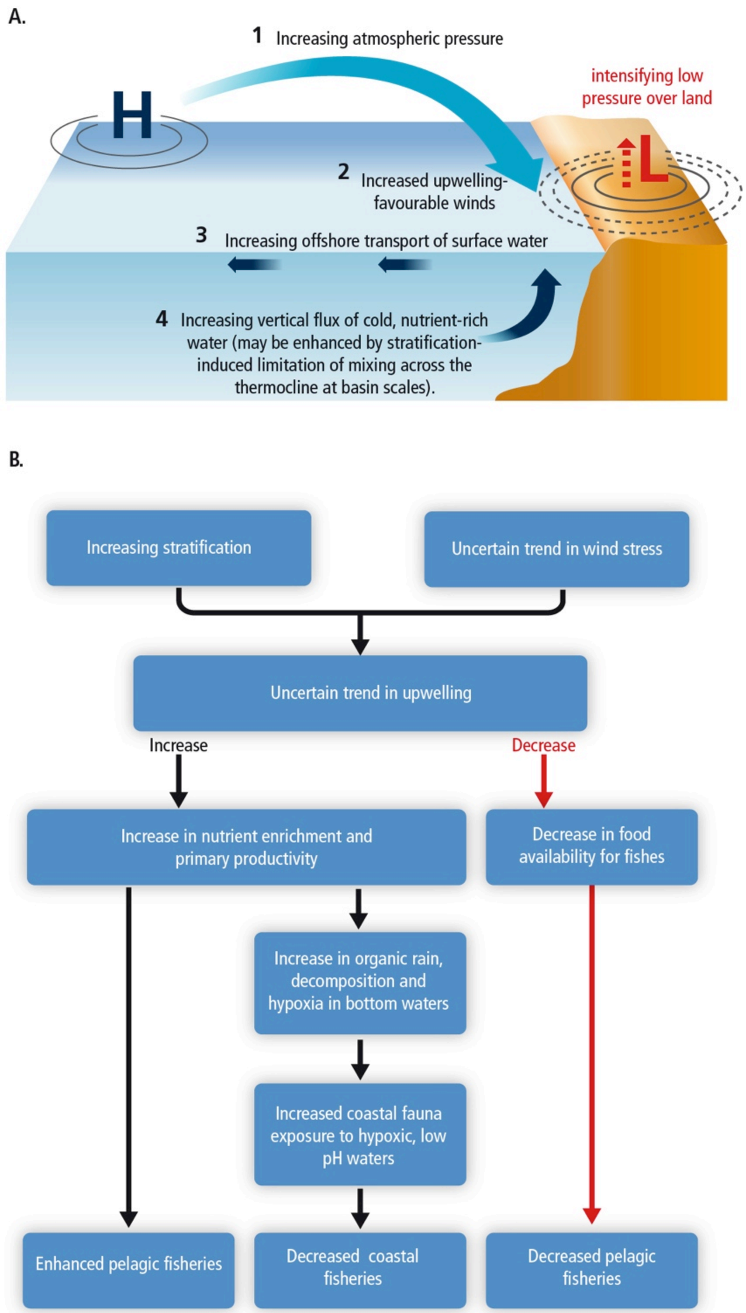


Figure UP-1: Upper panel: Schematic hypothetic mechanism of increasing coastal wind-driven upwelling at eastern boundary systems, where differential warming rates between land and ocean results in increased land-ocean pressure gradients (1) that produce stronger alongshore winds (2) and offshore movement of surface water through Ekman transport (3), and increased upwelling of deep cold nutrient rich waters to replace it (4). Lower panel: potential consequences of climate change in upwelling systems. Increasing stratification and uncertainty in wind stress trends result in uncertain trends in upwelling. Increasing upwelling may result in higher input of nutrients to the euphotic zone, and increased primary production, which in turn may enhance pelagic fisheries, but also decreased coastal fisheries due to an augmented exposure of coastal fauna to hypoxic, low pH waters. Decreased upwelling may result in lower primary production in these systems with direct impacts on pelagic fisheries productivity.

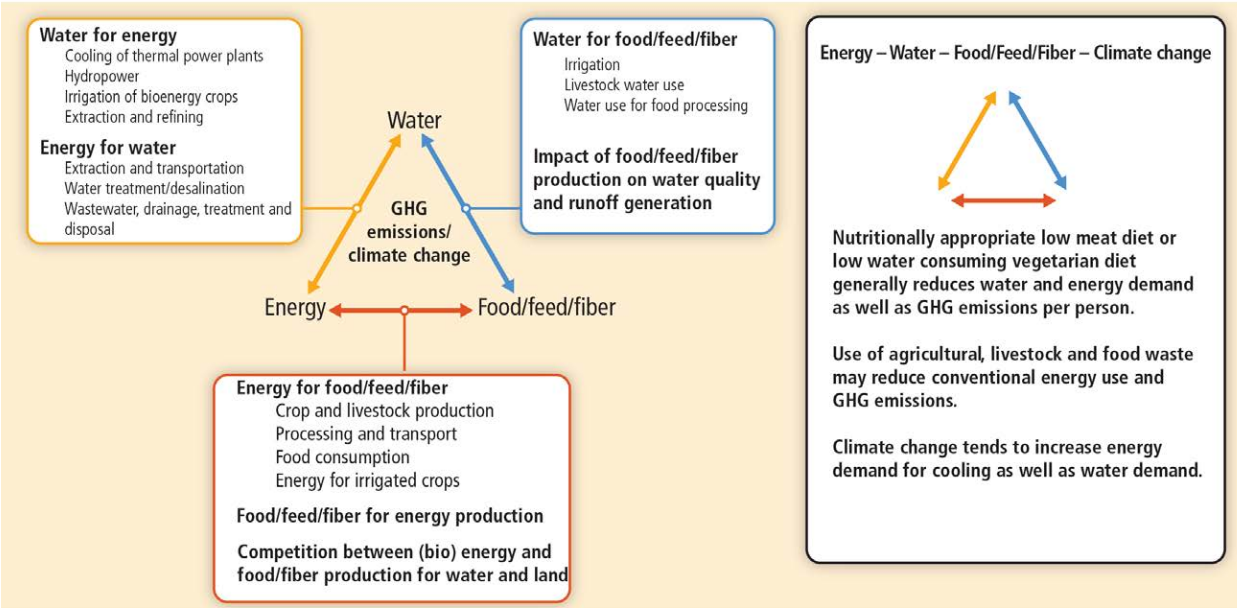


Figure WE-1: The water-energy-food nexus as related to climate change. The interlinkages of supply/demand, quality and quantity of water, energy and food/feed/fiber with changing climatic conditions have implications for both adaptation and mitigation strategies.