

**CONSERVATION STRATEGY
FOR THE
GREAT LAKES REGION
OF EAST AND CENTRAL AFRICA**

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Table of Contents

CHAPTER 5: CLIMATOLOGY OF THE EAST AFRICAN GREAT LAKES REGION AND POTENTIAL IMPACTS OF CLIMATE CHANGE ON ITS BIODIVERSITY AND ECOSYSTEM SERVICES	3
5.1 Climate change.....	3
5.2 Climates of the past, present and future.....	4
5.2.1 Regional paleoclimates	4
5.2.2 Present-day climate of the Great Lakes Region.....	9
5.3 Predicted changes in the future climate of the Great Lakes Region	19
5.3.1 Recent improvements in climate modeling.....	20
5.3.2 Projections for temperature.....	22
5.3.3 Projections for rainfall	23
5.4 Critical issues for biodiversity and Ecosystem Services.....	25
5.4.1 Adapting conservation practice and natural resource management.....	25
5.4.2 Species vulnerabilities related to climate change	27
5.4.3 Understanding impacts on Ecosystem Services.....	28
5.4.4 Predicting future ecological conditions	30
5.5 Conclusions	38
References.....	43

CHAPTER 5: CLIMATOLOGY OF THE EAST AFRICAN GREAT LAKES REGION AND POTENTIAL IMPACTS OF CLIMATE CHANGE ON ITS BIODIVERSITY AND ECOSYSTEM SERVICES

Introduction

The complex geography and latitudinal placement of the East African Great Lakes Region encompasses a diverse array of climates and climatic zones that have long shaped biodiversity distributions and human activities. Human-forced climate change presents the region with increasing stresses upon environmental systems and on the large and rapidly growing human populations that depend on them. As described in the most recent Intergovernmental Panel on Climate Change (IPCC) report, climate change will exacerbate existing environmental degradation in Africa, threatening the rich diversity of plant and animal species as well as the livelihoods of large populations of subsistence farmers, pastoralists, and even urban dwellers who rely on rural ecosystem-derived services for their water, electricity, and sustenance (IPCC, 2007: see in particular chapters by Boko *et al.*, 2007 and Christensen *et al.*, 2007). The warming of regional climates will be attended by changing rainfall patterns, changes in seasonality and an increase in the frequency of severe storm events, setting up further obstacles to the challenges of conserving biodiversity and the Ecosystem Services that people depend upon. On the human side, failing rains, increased flooding, and shifting conditions for key subsistence crops, natural resource species, and Ecosystem Services are expected to have profound impacts on many of Africa's people, with the poor and marginalized being particularly vulnerable (Ehrhart *et al.*, 2009).

5.1 Climate change

The term "climate change" as used in traditional climatology indicates climate parameter changes from baseline means established in recent decades, as well as changes in climate variability. In biodiversity conservation and development contexts, the term is almost universally used in reference to anthropogenically influenced climate change and its perturbation of "natural" climate and climate variability. The United Nations Framework Convention on Climate Change (UNFCCC) definition states that: *"Climate change" means a change of climate, which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods* (UNFCCC n.d.). By either definition, climate change represents building disequilibrium over time between climate, ecosystems and human livelihoods, forcing changes that affect and often threaten biodiversity.

Assessments of impacts performed at continental scale, such as those put forth by the IPCC tend to describe broad-scale characteristics of climate change, and thus miss the level of detail needed at site-specific (i.e. individual Key Biodiversity Areas (KBA)) and regional scales most applicable to biodiversity conservation across the Great Lakes

Region. An understanding of contemporary and historic climatology of East Africa is a necessary building block towards informed evaluation on how climate change may impact biodiversity and human wellbeing, including future socioeconomic development. This chapter therefore aims to offer a regionally focused perspective on climate change in contexts of biodiversity and Ecosystem Services. We begin by summarizing findings on past, present and future climates of the Great Lakes Region drawing upon source material from original scientific studies, as well existing reviews and compilations. We then utilize this information as the basis for assessing impacts on biodiversity, Ecosystem Services and humanity. We conclude with recommendations for interests concerned with biodiversity conservation and the services that biodiversity provides to humanity across the region.

5.2 Climates of the past, present and future

5.2.1 Regional paleoclimates

The well-developed paleoclimatic record for eastern Africa, when considered in contexts of the drivers of present day climatology, is an especially valuable resource for comprehending the magnitude and significance of changes projected in climate models. Greenhouse gas levels in the atmosphere now exceed 25% for carbon dioxide and 150% for methane over pre-industrial conditions, and have no parallel in at least 650,000 years (Siegenthaler *et al.*, 2005; Spahni *et al.*, 2005). Paleoclimate evidence suggests that global temperatures 3°C warmer than current conditions, which represents the mid-range of projections for later this century (IPCC, 2007), have not occurred since the Middle Pliocene geological stage (2.6-3.6 million years before present) (Salzmann *et al.*, 2009). Paleoclimate reconstructions also indicate that the current rate of warming forced by greenhouse gas emissions is an order of magnitude or greater than rates forced by natural events during the thermal increase following the Last Glacial Maximum (Joos and Spahni, 2008). Such projections are alarming, and imply that climate change will increasingly push biodiversity and the systems that depend upon it into unprecedented climatic realms (Williams and Jackson, 2007).

East Africa has been the subject of much recent attention by the paleoscience research community, yielding a wealth of insights into climatic changes extending many millennia into the past. Considerable inference has been developed from lake records based on geomorphology, sedimentology, stable isotope contents of primary lacustrine carbonates and organic matter, and biological remains (Gasse, 2000; Verschuren, 2004). More recently, long sedimentary cores extracted from lakebeds of several of the Great Lakes have been analyzed for new biochemical and molecular indicators of climatic variability, yielding relatively continuous proxy records of atmospheric and limnological conditions extending back 79,000 years from Lake Tanganyika (Scholz *et al.*, 2003) and 145,000 years from Lake Malawi/Niassa/Nyasa (Scholz *et al.*, 2011). These findings have been developed in parallel with significant improvements in understanding of contemporary climate and, taken together, these findings now provide substantial foundational knowledge for understanding the processes and consequences of the anthropogenic climate changes forecast for the 21st century.

Viewed from a longer-term paleoclimate perspective, the climate of the Holocene (the last ca. 12 thousand years) of East Africa is both anomalously warm and wet. Evidence from polar regions suggests that global temperatures have not been as warm as the present since the Eemian geological stage approximately 125,000 years ago (Hansen and Sato, in press). Ice age conditions dominated global climates for approximately 80-90% of the past 2 million years, and eastern Africa was characterized by cool, arid conditions, low lake stands, more extensive montane forests and a predominance of afro-montane vegetation that differ remarkably from current conditions (Marchant *et al.*, 2006; Cohen *et al.*, 2007). Historic lake level fluctuations reconstructed from the Lake Tanganyika and Lake Malawi/Niassa/Nyasa sedimentary cores and other paleorecords indicate that tropical East Africa was relatively dry during the Last Glacial Maximum (LGM: ~18-20 thousand years before present), humid during the early Holocene, and more recently relatively dry during the late Holocene leading to the present (Gasse, 2000; Verschuren, 2004). In this context it is important to recognize that contemporary perspectives on East African ecology are shaped on climatic conditions of the Holocene, a warm interglacial period extending over just 12 millennia, and which in paleo perspectives has been particularly favorable for both biodiversity and human habitation.

The forcing mechanisms underlying the large magnitude climatic changes experienced in multi-millennial time scales are now fairly well understood. These relate primarily to periodic variations in Earth's planetary orbit around the sun and the influences of corresponding changes in atmospheric circulations related to Ice Age glaciations at higher latitudes. The orbital changes cause changes in solar insolation of relatively modest magnitude, which nonetheless yield amplified responses from the growth of polar ice sheets and other factors that reconfigure global circulations (Gasse, 2000; Hansen and Sato, in press). Of particular concern in contexts of contemporary climate change is that the Holocene has been fairly quiescent globally with only minor orbital forcing changes and relatively static polar ice sheets, yet East Africa has nevertheless experienced large climatic fluctuations much stronger than those apparent in the historic record, which extends back less than two centuries (Gasse, 2000; Russell and Johnson, 2005). As recently as 5000 years ago large expanses of what is now the Sahara Desert were grasslands until changes in orbital forcing weakened moisture import to the region (deMenocal *et al.*, 2000). Modern vegetation diversity and distribution patterns only became established during the Holocene, and it follows that all extant species must have persevered and responded to the environmental stresses accompanying the climatic transitions to current conditions.

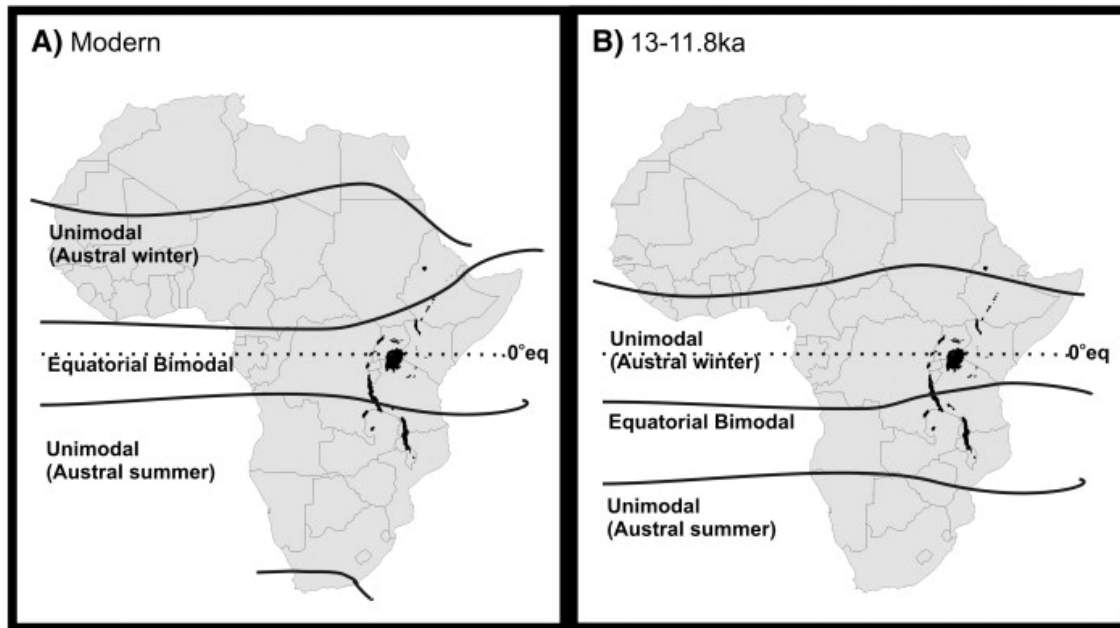
The comprehensive histories being developed from past epochs therefore provide considerable insight into the inherent instability of East African climates, and how future climatic changes may in turn drive ecological responses affecting biodiversity throughout the African tropics and elsewhere. Quantification of the magnitude and duration of past changes in tropical precipitation, temperature, vegetation and hydrology and their linkages to changes in climatic forcings provides a strong foundation for comprehending how changes in radiative forcing caused by greenhouse gases may drive changes in eastern Africa. The paleo records indicate that on all timescales, climate changes in the African tropics reflect broader scale disruptions in the Earth's climate system (Gasse,

2000). The long time series developed from accumulated sediments in Lake Malawi/Niassa/Nyasa and Lake Tanganyika are among the best resolved indicators of past climate in the tropics, and offer particularly detailed insight into changes in temperature, vegetation, hydrological balance and lake levels (Cohen *et al.*, 2007; Scholz *et al.*, 2007; Scholz *et al.*, 2011; Tierney *et al.*, 2008; Konecky *et al.*, in press).

These responses to atmospheric conditions are in turn related by investigators to changes in atmospheric circulations, and located in the timelines and contexts of other paleoclimatic data sets from around the world. As an example, Figure 5.1 shows a schematic depiction of seasonal rainfall modes across the African continent in the present and as reconstructed near the end of the Pleistocene 13,000-11,800 years before present. This shows that the twin wet-season rainfall pattern experienced at present across the equatorial belt (and most of the Great Lakes Region) was depressed far to the south at the end of the Pleistocene, when it was centered across the latitudinal range of Lake Malawi/Niassa/Nyasa (Ivory *et al.*, 2012). During this period (known as the Younger Dryas), a temporary reversal to colder conditions occurred during the multi-millennial warming following the Last Glacial Maximum. The shifts in seasonality, along with cooler temperatures, represent an entirely different distribution of climatic zones across the entire Great Lakes domain than that of the present, which can be inferred to have been associated with comparably different biodiversity distributions. Stratigraphic evidence from sediment cores suggest that Lake Victoria dried out completely around 15,000 years before present, and then partially filled before declining again during the Younger Dryas episode (Stager *et al.*, 2002).

Figure 5.1 Basic precipitation regimes in Africa

A) Continental scale depiction of basic precipitation seasonality regimes showing the present-day latitudinal extent of summer unimodal (one wet season) and bimodal (two wet seasons) rainfall zones in tropical Africa. B) Latitudinal extent of summer unimodal and bimodal rainfall zones in tropical Africa from approximately 13,000 to 11,800 years before present as inferred from pollen records. Figure reproduced from Ivory *et al.* (2012).

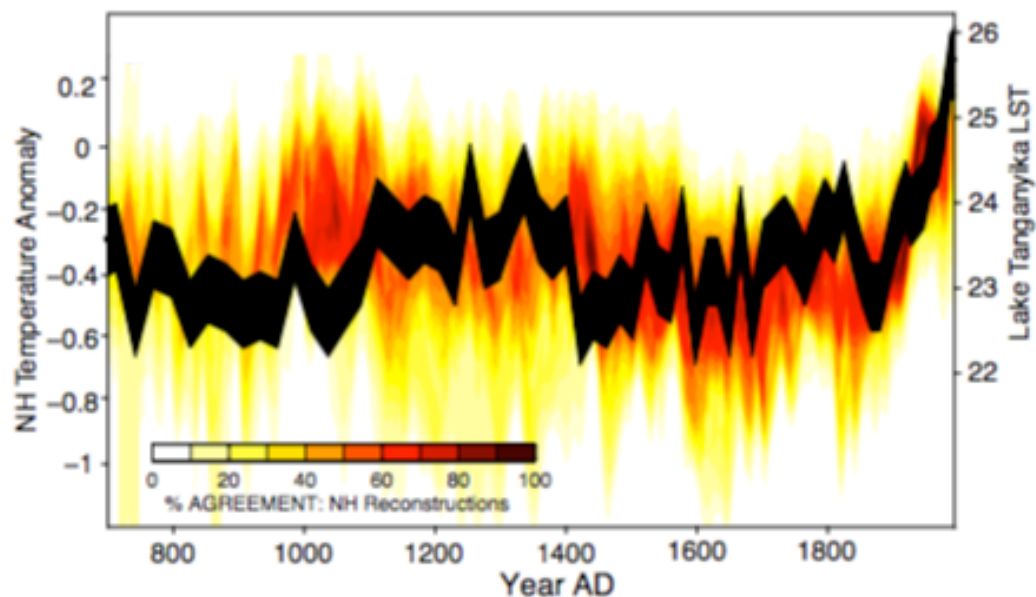


Regional paleotemperature reconstructions have been developed from pollen records and molecular tracers preserved in lake sediments. Pollens show that one-hundred-thousand-year scale glacial periods have been dominated by afromontane species, indicating downward extension of the high altitude tropical biome from temperatures 4-5°C lower than present in cold epochs (Marchant *et al.*, 2006; Vincens *et al.*, 1993; Bonnefille and Chalé, 2000). Similar results have been yielded from analysis of molecular temperature proxies from sediment cores in lakes Tanganyika and Malawi/Niassa/Nyasa (Powers *et al.*, 2005; Tierney *et al.*, 2008). Paleolimnological reconstructions show that the changes in temperature and precipitation regimes have invariably yielded major changes in hydrology of the Lake Basins, manifested by changes in lake levels that by far exceed changes observed in recent experience (Alin and Cohen, 2003; Tierney *et al.*, 2008; Scholz *et al.*, 2007; Scholz *et al.*, 2011). A highly resolved multi-centennial proxy record of Lake Tanganyika surface temperature variations displays considerable agreement with reconstructions of Northern Hemisphere temperature behavior for much of the past 1300 years, again an indication that thermal trends in East Africa are driven by global-scale forcings (Tierney *et al.*, 2010) (Figure 5.2). The post-industrial warming of the global atmosphere is synchronous with an increase of more than 2°C in Lake Tanganyika's surface temperature, which is now considerably warmer than at any point in this time series. The warming has occurred far more rapidly at the surface than in the deeper waters in the lake, which increases the thermal stability and diminishes mixing of surface and deep waters causing reductions in nutrient transport to the surface (Verburg *et al.*, 2003; Verburg and Hecky, 2009; Tierney *et al.*, 2010).

Figure 5.2 Reconstructed surface temperature anomalies in Lake Tanganyika

Lake Tanganyika reconstructed surface temperature compared with Northern Hemisphere reconstructed temperature trends since A.D. 700. Lake Tanganyika surface temperature is shown in black, including standard deviation error is plotted over the composite Northern Hemisphere temperature anomaly

reconstructions (Jansen *et al.*, 2007). Colors represent the percent of agreement between the time series. Reproduced from Tierney *et al.* (2010).



Key lessons developed from paleoclimate studies relevant to contexts of 21st century climate change over the Great Lakes Region can be summarized as follows:

- The contemporary climate of East Africa even before anthropogenic influences became apparent is an anomaly relative to conditions over geologic time scales. Climatic conditions during the Holocene, the current geological epoch that began around 10,000 BC, have been anomalously warm and wet compared to most of the Pliocene-Pleistocene periods (the last 5.3 million years) that preceded it. It is likely that the region is now warmer than at any time since the Eemian Stage, approximately 125,000 years ago.
- All extant species must have persevered and responded to the environmental stresses accompanying the transitions to current conditions and the considerable hydrological variability that has characterized the Holocene.
- The climates of the African tropics are inherently unstable: global climate perturbations yield amplified responses, particularly in hydrology and precipitation seasonality, across East Africa.
- The Holocene has been characterized by relatively stable global climate conditions relative to the past, yet major hydrological changes have nonetheless occurred in East Africa marked by significant variations in lake levels.
- The high degree of response of the great lakes to climatic changes of the past exhibited in paleo records provides convincing evidence that anthropogenic warming and related hydroclimatological changes will result in major changes in lake hydrology.
- Pollens and other biotic indicators confirm large major climatic shifts in the past have been associated with major vegetation transitions across the region.

- The paleo record demonstrates that past climate changes have completely rearranged the placement of climatic zones across landscapes, causing rearrangements of species assemblages and distributions that differ greatly from the present.

5.2.2 Present-day climate of the Great Lakes Region

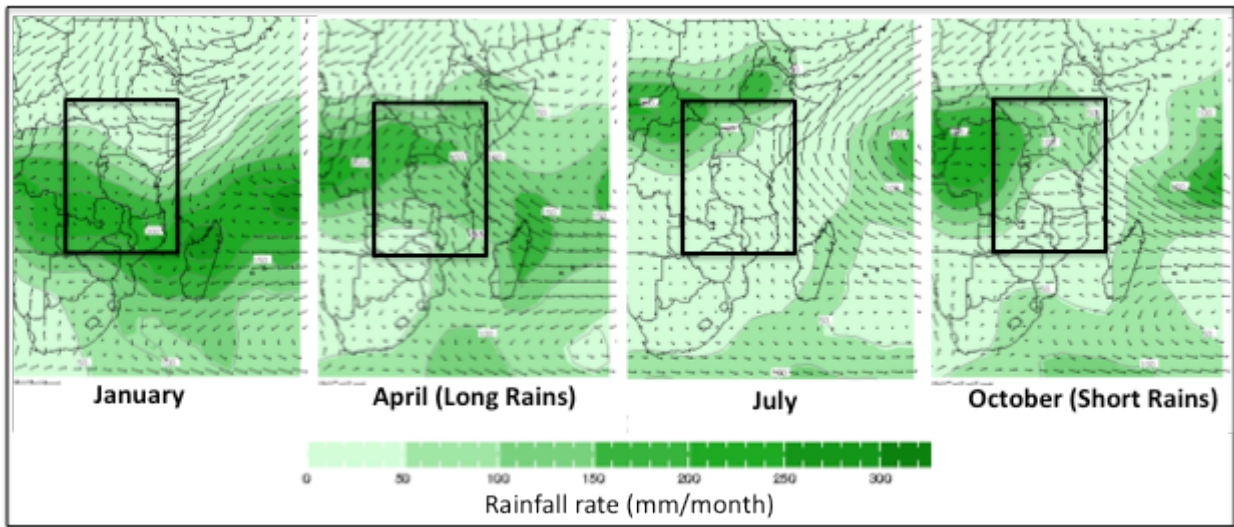
In this section we present an overview of the contemporary climatology of the Great Lakes Region, incorporating new findings that significantly improve understanding on characteristics of climates internal to the region and the external forcing factors that control climatic variability and trends. The past decade has seen major advances in understanding of the atmospheric and oceanic factors that are the principal drivers of climatic variability across East Africa. While climate research focused in tropical Africa has long been hindered by poor availability of systematic, quality-controlled climate data (Collins, 2011), new tools and analysis techniques such as satellite-based rainfall monitoring and lake level altimetry are helping to overcome some of the major limitations. Expansion of on-the-ground observational networks remains a pressing need, however (Seimon *et al.*, 2011).

a) Overview

The climatic regimes of the East African Great Lake basins vary considerably as a function of location. Topographic features, basal elevation and latitudinal range shape the primary characteristics of the individual Lake Basins yielding a wide range of climatic characteristics that exert strong control over biodiversity distributions and human activities. The annual cross-equatorial migration of the Intertropical Convergence Zone (ITCZ), a belt of persistent cloudiness and rainfall, largely dictates climate seasonality and precipitation delivery (Figure 5.3). A single wet season is experienced annually in both the northern and southern part of the Great Lakes Region phased 6 months apart, with a broad belt between them across equatorial East Africa experiencing twin wet seasons in the form of the “Long Rains” (March-May) and “Short Rains” (September-November).

Figure 5.3 Precipitation climatology and water vapor transport over eastern Africa

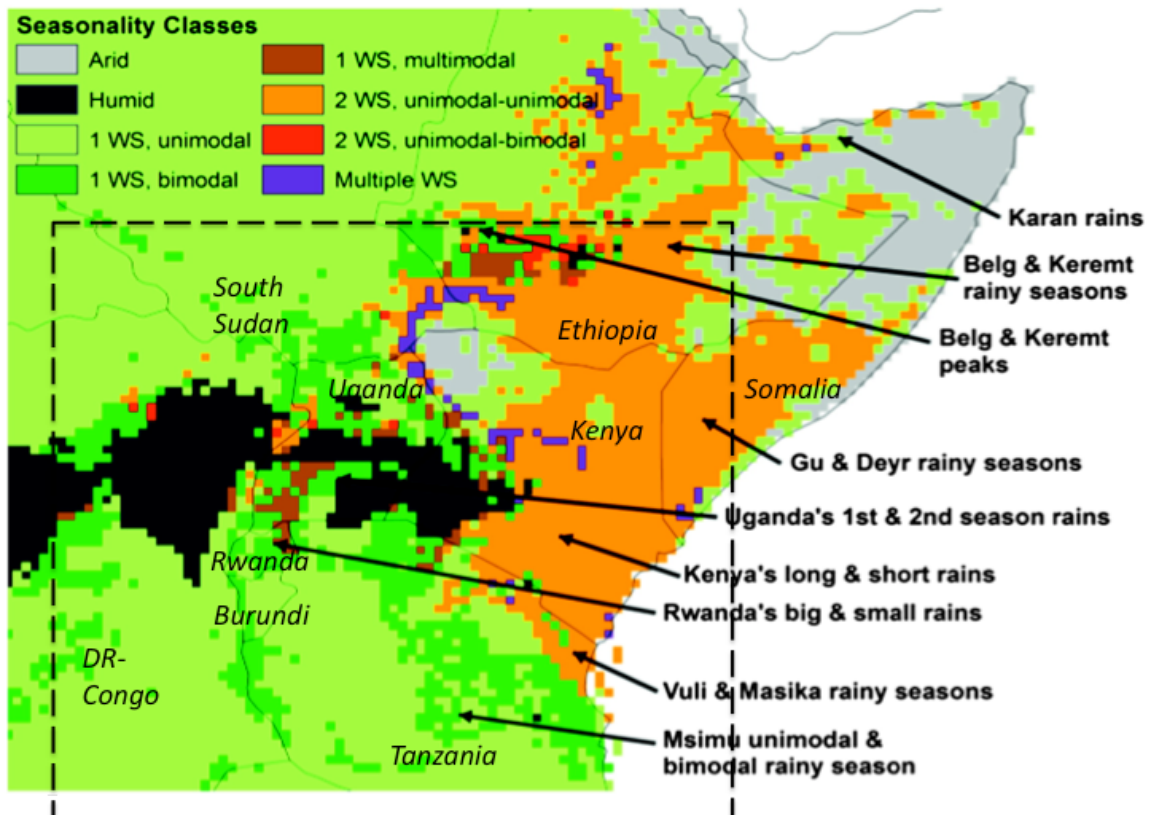
Precipitation climatology and water vapor transport over eastern Africa at 3-month intervals according to monthly averages of rainfall rate (green shades, 50 mm contour interval) derived from global analysis products. Also indicated are wind fields for the 925 hPa pressure level (approximately 800 m above sea level, arrows), with wind speed proportional to arrow length. The black rectangles outline the Great Lakes domain. The annual north and south migrations of the Intertropical Convergence Zone (ITCZ), evident as the darker green shades over equatorial regions, bring the Short and Long Rains to the northern part of the rift region around October and April, respectively, while southern parts of the domain experience a single long-duration wet season peaking around January when the ITCZ is at its southern zenith. In this depiction the true complexity of rainfall distributions related to topography and surface landforms such as the East African Great Lakes are not apparent. Source: International Research Institute for Climate and Society, http://iridl.ldeo.columbia.edu/maproom/Regional/Africa/Climatologies/Precip_Loop.html



Past efforts to map seasonality and climatic domains based on cluster analysis of rain gauge measurements identified several sub-regions with common characteristics (Nicholson *et al.*, 1988; Ogallo, 1989; Indeje *et al.*, 2000). New satellite-based observations from the Tropical Rainfall Measuring Mission (TRMM) have allowed spatially continuous mapping of precipitation occurrence that reveal a more detailed and spatially heterogeneous picture (Herrmann and Mohr, 2011). As shown in Figure 5.4, which covers most of the northern and central parts of the Great Lakes Region, rainfall seasonality is actually very complex, with high spatial variability that is maximized in a broad belt extending westward along the equator from central Kenya. Furthermore, the TRMM data allows categorization of the rainfall into a range of subclasses offering improved representation of site-specific climate typologies. These show that the simple one- versus two-wet-season categorization outlined in the previous paragraph can be broken down into subclasses based on intra-seasonal rainfall distributions. Such level of detail is almost impossible to ascertain from existing rain gauge networks: this points to the limitations of applying spatial interpolations developed on point observations from rain gauge networks alone (e.g. *WorldClim*: Hijmans *et al.*, 2005) to characterize local-scale rainfall patterns in space and time.

Figure 5.4 Complexity of rainfall seasons across the northern Great Lakes Region

Annual rainfall seasonality regimes across East Africa at 0.25 degree spatial resolution (~30 km) based on 12 years of satellite observations by the Tropical Rainfall Measuring Mission (TRMM). The color scheme indicated by the legend shows perpetually dry and wet regimes (arid, humid classes), and seasonal regimes characterized as single- (1WS), dual- (2WS) and multiple-wet-season regimes, the peak rainfall modes occurring within those seasons. Local names are indicated to show the correspondence of the map with local manifestations of wet seasons. The dashed box encompasses the northern part of the Great Lakes domain. Modified from Herrmann and Mohr (2011).

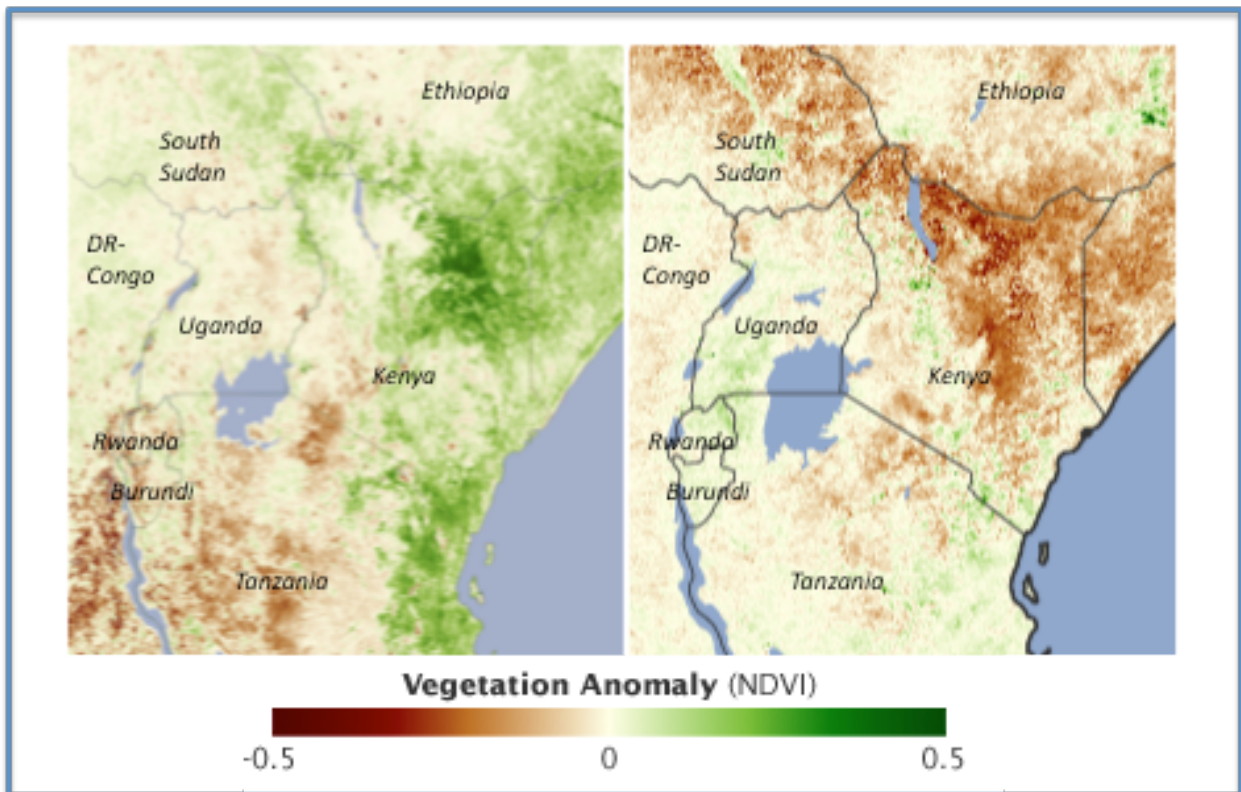


Mean temperatures throughout the Great Lakes Region are largely a function of elevation throughout the domain, though the lake environs are also moderated by heat retention of

the large water bodies. Little thermal seasonality in monthly mean temperature is evident across the equatorial belt, but southern regions of Lakes Malawi/Niassa/Nyasa and Tanganyika experience a marked dry season with reduced humidity and cloud cover in the austral winter months that is associated with lowered nocturnal minima (Seimon and Picton Phillips, 2012). Climatic variability and seasonality across the Great Lakes are therefore most evident in moisture variations, in cloudiness and precipitation occurrence, and in the corresponding hydrological responses of river flows, lake level and vegetation. Seasonal anomalies such as droughts and floods tend to be regionally synchronous phenomena across spatial domains larger than the individual basins comprising the Great Lakes Region (Lyon and DeWitt, 2012; Anyamba *et al.*, 2002) (Figure 5.5). Such patterns offer clear indications that climatic variability at seasonal to annual time scales is modulated to a considerable degree by broad-scale factors that operate regionally.

Figure 5.5 Vegetation anomalies in East Africa (2006 and April-June 2011)

Vegetation anomalies relative to mean conditions from November 2006 (left) and April-June 2011 (right) according to the Normalized Difference Vegetation Index (NDVI). Abundant Short Rains in 2006 yielded richer than average vegetation cover (positive NDVI anomalies, green shades), whereas failure of the Long Rains in 2011 caused a severe drought, seen as negative NDVI anomalies (brown shades) that resulted in a humanitarian catastrophe across the Greater Horn region. Source: NASA Earth Observatory (<http://earthobservatory.nasa.gov/>)



b) Teleconnections and the importance of ocean temperatures

These broad scale anomalies result from external climatic forcings that originate well outside the region through global linkages known as teleconnections (Diaz *et al.*, 2001). Year-to-year precipitation variability is most strongly influenced by annually varying sea

surface temperature patterns in the Atlantic, Indian and Pacific Oceans. Until very recently it has been thought that interannual variability is controlled primarily by the El Niño Southern Oscillation (ENSO) which, despite being focused in the eastern equatorial Pacific Ocean, exerts considerable influence over rainfall occurrence in eastern Africa (Camberlin *et al.*, 2001; Anyamba *et al.*, 2002; Schreck and Semazzi, 2004; Giannini *et al.*, 2008). The general pattern links warm ENSO (El Niño) events with regional rainfall surpluses, and cold ENSO (La Niña) events with rainfall deficits; this pattern is inconsistent, however, since a more local factor, the Indian Ocean Dipole (IOD: Saji *et al.*, 1999), must act in concert with ENSO in order to yield the expected rainfall anomalies (Black *et al.*, 2003; Marchant *et al.*, 2006). Large-magnitude events of both warm ENSO and the positive phase of the IOD that come with greater-than-average sea-surface temperatures occurred in 1997-98, causing the wettest year in decades and widespread flooding (Anyamba *et al.*, 2002); the opposite conditions in 2011 yielded an exceptionally dry year, with severe regional impacts including the exacerbation of political instability across the Great Horn region (refer to Figure 5.5). The interconnectedness of East African climate to the global circulation is evident through other teleconnections too. Rainfall variability in the Greater Horn of Africa region including northern parts of the Great Lakes Region has been shown to correlate remarkably well with surface pressure over the Indian subcontinent and the onset date of the Indian Monsoon (Camberlin, 1997; Camberlin *et al.*, 2010); such factors in turn relate to the complex ENSO-Indian Ocean temperature variations described above.

The relative importance of ENSO versus the IOD over East African climatic variability has yet to be firmly established, and this uncertainty is important to consider when evaluating model projections for the future. At longer time scales, oceanic control over inter-decadal trends in East African rainfall has been proposed by Black *et al.* (2003), with suppressed rainfall during the decades of the 1940s and 1960s related to suppressed activity (relating to sea surface temperature) of both the IOD and ENSO. Studies focusing on the September-November Short Rains confirm the importance of Indian Ocean sea surface temperatures and ENSO in East African rainfall variability (Goddard and Graham, 1999; Black *et al.*, 2003). The importance of the IOD is particularly evident when its positive phase (associated with greater-than-average sea-surface temperatures) is strongly developed, such as in 1961, 1994 and 1997 when excessive rainfall occurred across much of eastern Africa (Ummenhofer *et al.*, 2009); as in other studies, this relationship is only unambiguously present for the Short Rains. Such strong relationships are not found for the Long Rains (Camberlin and Philippon, 2002), which is discouraging for long-term predictability given that the Long Rains generally contribute a greater fraction of annual rainfall than the Short Rains.

c) Influence of landforms and landcover

An important element of regional climatic organization is the effect of prominent landforms such as the rift valleys and great lakes on atmospheric circulations, particularly with regard to convective storms that provide most rainfall across the region (Anyah *et al.*, 2006; Hession and Moore, 2011). In the environs of Lake Turkana, a prominent topographic defile that cuts across the East African highlands creates a semi-permanent high-velocity southeasterly wind current that blows from the Indian Ocean basin towards the Sahara Desert throughout the year. This shallow low-level jet stream, termed the Turkana Jet (Kinuthia and Asnani, 1982), frequently reaches extremely high velocities

and is instrumental in sustaining the aridity of the Chalbi Desert and other lowland areas of the Turkana basin, as well as the exceptionally high evaporative losses from the lake surface (Avery, 2010). Over Lake Victoria, a different type of circulation that owes its existence to the exceptional size and heat storage of the lake itself is a persistent convection cell that develops nocturnally over the lake, producing what might be the highest rainfall found anywhere across the region (Anyah *et al.*, 2006). For both the Turkana jet and Lake Victoria rainfall maximum, the landforms and lake extents are determining factors underlying highly defined climatic responses. This highlights the need for comparable spatial resolution in atmospheric models to properly represent such features.

Land cover is an important determinant of local climate conditions (and *vice versa*). The high degree of anthropogenic disturbance over much of the land surface in the Great Lakes Region has caused changes in radiation and moisture transfers between land and atmosphere that significantly affect local climatic conditions. Conversion of forest to croplands or grasslands strongly affects absorption of sunlight, local heating and cooling rates related to evapotranspiration and moisture recycling between the surface and the atmosphere (Jackson *et al.*, 2008). A point of some debate concerns the relative roles played by internal factors such as Land Use/Land Cover (LULC) changes versus external forcing factors in determining multidecadal trends in rainfall widely observed throughout tropical Africa, most notably in the Sahelian region but also in eastern Africa (Giannini *et al.*, 2008). Coupled oceanic-atmosphere climate modeling suggests that the trends are externally dictated by sea surface temperature variations, whereas findings from regional modeling studies determine that internal forcing by anthropogenic land cover change within the continent itself may explain the trend behavior (Giannini *et al.*, 2008; Paeth *et al.*, 2009). Both factors are very likely at work: understanding to what degree proportionally is of considerable importance in assessing climate model predictions and improving model representations of both forcings and responses. The fact that LULC changes are anthropogenically driven and can be directly managed makes this understanding all the more important, especially in the context of conservation where collateral damage to biodiversity can be dramatic.

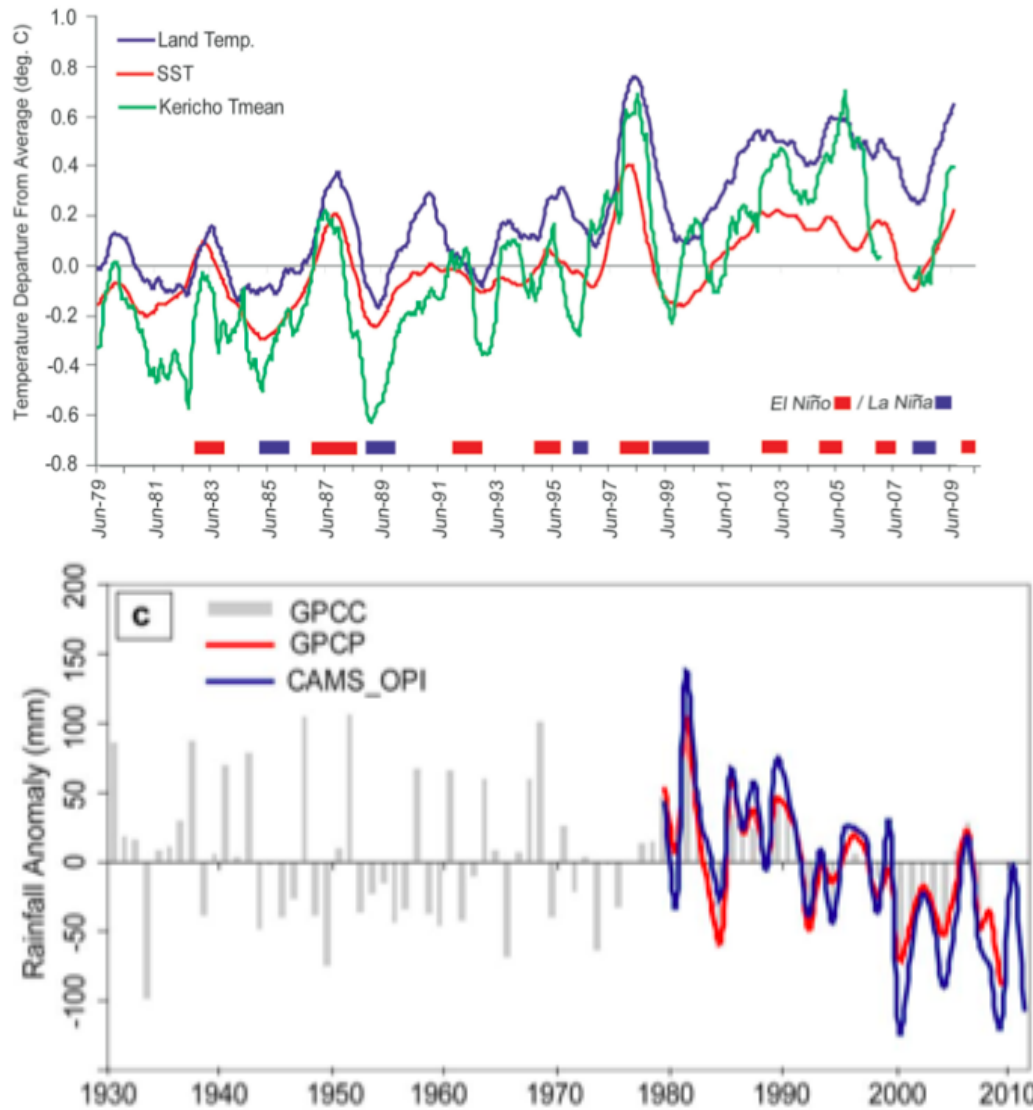
d) Contemporary temperature trends

Like virtually all terrestrial environments globally, eastern Africa is experiencing a pronounced multidecadal warming trend that began more than a century ago and has accelerated in recent decades. Global surface temperatures increased by approximately 0.7°C from 1880-2000, and have been rising rapidly at 0.15-0.20°C per decade since the 1970s (Hansen *et al.*, 2010). While the warming trend likely represents responses of the global atmosphere to both natural and anthropogenic forcings, the latter group, driven by greenhouse gas concentrations and land use change, has emerged as the dominant driver of the warming (IPCC, 2007; Meehl *et al.*, 2011). For the African continent, a recent assessment of temperature trends since 1979 suggests that tropical temperature variations related to tropical forcings such as ENSO, which causes short-term warm anomalies throughout low latitudes, do not explain the warming, pointing to a significant anthropogenic contribution (Collins, 2011). Furthermore, temperature anomalies at seasonal (~3-monthly) through decadal scales across East Africa show a high degree of correspondence with global patterns in tropical sea surface and land area temperatures

(Figure 5.6). Smoothed tropical land and sea surface temperature departures observed around the globe correlate strongly ($R=0.88$ for 11-month running means); remarkably, observations at a single site, Kericho in western Kenya, correlate almost as strongly with each of them ($R=0.82$ for sea surface temperature; $R=0.87$ for tropical land temperature) (Omumbo *et al.*, 2011). The time series shown in Figure 5.6 indicates the high degree of control that tropical climate forcings, particularly the linked ocean-atmosphere anomalies accompanying ENSO events, have over inter-annual temperature variability and the net warming trends experienced across eastern Africa.

Figure 5.6 Recent trends and variability in temperature and precipitation

(Left) Thirty years of point observations from a single site in western Kenya demonstrate a high degree of correspondence with global-tropical land and sea surface temperatures (SST). In this graph, the time series of monthly departures from 1980-2009 mean values ($^{\circ}\text{C}$) with an 11-month moving average applied are shown for Kericho, Kenya (T mean, green line), global tropical sea surface temperatures between 25°S - 25°N (red line) and tropical land area mean temperature (blue line). Color bars at the bottom of the figure show the occurrence and duration of warm and cold ENSO events (i.e. El Niño and La Niña). The common patterns in the data are indicative of the significant control that global climate forcings have over temperature trends at annual to decadal scales in the Great Lakes Region. **(Right)** A recent downward trend has been identified in the Long Rains season across East Africa. This plot shows the time series of area-averaged March-May precipitation departures from a 1979–2010 base period average (in mm) as compiled from data series utilizing rain gauges alone (GPCC) and merged analysis of station rainfall observations and satellite estimates (GPCP, and CAMSOP1). Sources: (left) reproduced from Omumbo *et al.*, 2011; (right) reproduced from Lyon and DeWitt, 2012.



Analysis of multi-decadal temperature trends from long-term station observations in Kenya and Tanzania shows a significant rise in nocturnal minima, but no trend in diurnal maxima (Christy *et al.*, 2009); these patterns therefore match signals from many other terrestrial environments (IPCC, 2007). The most compelling evidence from the Great Lakes Region that the atmosphere is in the midst of a secular trend of anomalous warming beyond recent experience is derived from sediments on the floor of Lake Tanganyika (Tierney *et al.*, 2010) (refer to Figure 5.4). The deglaciation of East Africa's highest peaks – the Rwenzori mountains and Mts. Kenya and Kilimanjaro - relate at least in part to the rise in atmospheric freezing level (i.e. the 0°C isotherm) accompanying the recent warming (Diaz *et al.*, 2003; Taylor *et al.*, 2006), although cloud cover and precipitation variations are contributing factors as well (Russell *et al.*, 2008; Mölg *et al.*, 2006). While the disappearing glaciers have received widespread media attention as icons of global climate change impacts in East Africa (Carey, 2007), their minor extent

suggests that their diminution is actually of little hydrological or ecological consequence (Kaser *et al.*, 2004).

e) Contemporary precipitation trends

Observational studies and model simulations identify that the southern Indian Ocean is the primary source for water vapor that falls as rain throughout the Great Lakes Region (refer to Figure 5.3). Some rainfall also originates from airstreams of Atlantic origin after passage through the Congo basin (Latif *et al.*, 1999; Nicholson, 2000; Tierney *et al.*, 2011). Unlike temperature trends, which offer coherent and consistent patterns of warming across time and space, precipitation trends reported for the Great Lakes Region are often inconsistent with one another, making an overall assessment inconclusive (e.g. Stampone *et al.*, 2011). Much of this relates to the lack of a single spatial domain being considered, different time windows evaluated and the overall lack of data from quality-controlled rain gauge records. Some of the confusion may also be explained by the high spatial variability in precipitation seasonality recently identified by Herrmann and Mohr (2011) and illustrated in Figure 5.4, with net increases and decreases in rainfall being substantially related to local scale effects rather than external forcings alone. Furthermore, the differences in forcings underlying the interannual variability in the Short Rains, which are now well understood, and the Long Rains, which are less understood, suggest that their respective seasonality characteristics and trends should be evaluated independently (Hartter *et al.*, in press). New results assessing the recurrent failure of the Long Rains since 1999 identify a downward trend in that season's rainfall and implicate a dynamic response to oceanic forcing as the dominant causative factor (Lyon and DeWitt, 2012) (Figure 5.6).

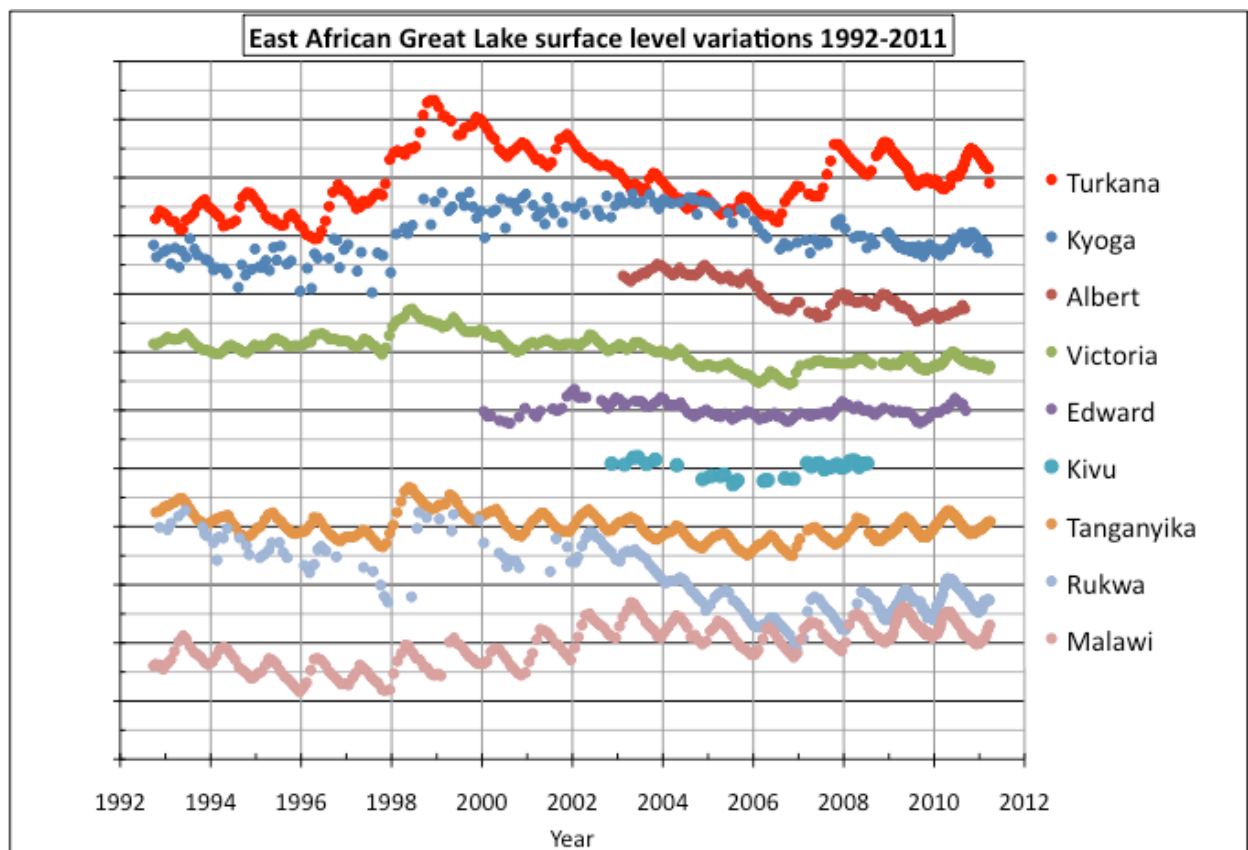
f) Lake level responses to climatic variability

A clearer picture is derived from observations and reconstructions of the individual Great Lakes: owing to the integrative effects of their large basin catchments and buffering of hydrological inflows and outflows, these display dampened but coherent trends. As outlined in Chapter 1 (section 1.2), the Lake Basins each have distinct geographic characteristics, which are important factors in their respective responses to externally forced climatic variations. The lake levels display highly synchronous behavior across large spatial extents, though with widely differing amplitudes (Figure 5.7). Synchronous behavior across the Lake Basins is evident in marked rises in 1997-98 and relatively low lake stands in 2006, reflecting responses to the wet and dry precipitation anomalies discussed above, respectively. Pronounced seasonal rise and fall cycles are clearly evident away from the equator (at Lake Turkana in the north, and Tanganyika, Rukwa and Malawi/Niassa/Nyasa in the south) reflecting the unimodal precipitation seasonality. In contrast, Lakes Kyoga, Albert, Victoria, Edward and Kivu, where two wet and dry seasons occur annually, do not exhibit such signals. The individual lakes show widely varying rates and amplitudes of change, with Lake Turkana being the most variable including a measured increase of 5 meters in just 3 years (1996-99); records extending back to 1893 indicate that the lake has fallen approximately 20 meters from a peak reached at the end of the 19th century (Kallqvist *et al.*, 1988). Inference on long-term precipitation trends over East Africa derived from lake-level reconstructions suggests that the region is naturally prone to prolonged wet and dry epochs, and that Holocene variability, while seemingly large, is actually small compared to that experienced during glacial periods, when surface levels of Lakes Tanganyika and Malawi/Niassa/Nyasa

fluctuated by hundreds of meters, and Lake Victoria might have dried up and refilled multiple times (Gasse, 2000; Scholz *et al.*, 2007, 2011). In contrast, Lake Tanganyika's measured variations during the 20th century only ranged by 4.2 meters (Alin and Cohen, 2003). The propensity of the lakes to experience such fluctuations implies high susceptibility for profound hydrological changes across the region as anthropogenic climate change perturbs the already unstable natural variability.

Figure 5.7 Two decades of East African Great Lakes surface variations

High temporal resolution lake level observations from satellite altimetry for nine Great Lakes between 1992-2011. The levels indicated are departures (in m, horizontal lines) relative to the period means from data available for each lake. Data from Hydroweb: www.legos.obs-mip.fr/fr/soa/hydrologie/hydroweb/Cartes/Afrique_Est.html



Key lessons developed from studies on contemporary climatology relevant to contexts of 21st century climate change over the Great Lakes Region can be summarized as follows:

- A secular trend of rapidly increasing temperatures is currently in progress and consistent with expectations of anthropogenic greenhouse gas-induced warming.
- The most significant warming in climate observations is evident in daily minimum temperatures, whereas daytime maxima show little evidence of a trend.

- Seasonal-annual scale temperature anomalies in East Africa follow patterns experienced around the global tropics that are largely the atmospheric response to ENSO-related warming and cooling of the equatorial Pacific Ocean.
- Seasonal to inter-annual rainfall anomalies are driven by atmospheric circulation adjustments to linked atmosphere-ocean climate patterns well outside the region, involving the Pacific, Atlantic (ENSO) and Indian (IOD) Oceans.
- Studies show that the seasonal Long Rains and Short Rains, which affect much of the Great Lakes Region, are not mirror images of one another, but instead distinct phenomena influenced by different forcings.
- Short rains show a clear linkage to ENSO events and IOD events but this is less clear for the Long Rains which have shown an overall drying trend in the last two decades.
- Lake basin hydrology, and particularly lake surface levels and temperatures, have a high propensity for rapid response to changing climatic conditions.
- The responses of individual Lake Basins to climatic variability vary significantly due to their different basin geometries (particularly the lake-area-to-basin-area ratios), rainfall seasonality (one vs. two wet seasons annually), and related characteristics that cause some lakes to have highly amplified responses.
- Distinct localized climates such as the aridity and high winds of the Omo/Turkana Basin and the nocturnal convection over Lake Victoria originate from the interaction of atmospheric flows and prominent landforms.

5.3 Predicted changes in the future climate of the Great Lakes Region

Anticipating the future climatic states and associated consequences to biodiversity and human development across the Great Lakes Region requires interpretation of climate model projections placed in contexts of past and present climatic trends and variability. It also requires recognition that climate change is not a single driving force, but is the outcome of distinct components acting concurrently across a range of spatial and temporal scales. The recognized controls over East African climates developed from studies of past and present-day conditions suggest that three distinct types of changes collectively will determine climatic evolution at local to regional scales across the Great Lakes Region as time progresses.

First, there are **secular trends** related to the changes in radiative forcing associated with the global buildup of anthropogenic greenhouse gas emissions. These result in changes that occur relatively uniformly at regional scales (e.g. across East Africa), and for temperature increase in particular. An intensification of the hydrological cycle is in turn a consequence of the thermal increase due to the exponential increase in water vapor capacity as a function of temperature. In a warming atmosphere, this physical property of air increases both the intensity of precipitation and the rates of evaporation. This also holds for compositional changes of air itself, with the increase in CO₂ and its importance in driving changes in photosynthesis (CO₂ fertilization) occurring in proportion to current

levels throughout the region. The climatic changes for these relatively direct consequences of greenhouse gas buildup are therefore quite clear: only the rate and ultimate magnitude of change remain uncertain.

Second, the changes in radiative forcing due to greenhouse gas buildup at global scales are driving **changes in large-scale atmospheric and oceanic circulations** that operate as external forcings on East African climates. As described above, such circulations (ENSO, IOD) have been demonstrated to be the key drivers of seasonal to inter-annual precipitation and temperature variability across East Africa. Coupled ocean-atmosphere models offer considerable insight into how the circulations and related phenomena might change, but confidence is far lower regarding the specific changes, especially with respect to the Long Rains. Therefore, until it can be clearly demonstrated how radiative forcing changes are likely to affect these dynamic drivers of climatic variability across East Africa, interpreting trends in climatic variability generated by predictive models, particularly for spatial and temporal distributions of rainfall, will require considerable caution.

Finally, **land use/land cover changes** are significant drivers of climatic change at local scales, but also in aggregate for the whole region. Changes in land surface type drive important changes in radiative transfers, evapotranspiration and runoff. Conversion of forests to croplands in particular causes marked changes in climatological characteristics across the deforested areas.

A comprehensive survey of findings on climate change and its impacts in Africa is provided in the IPCC report¹ (Christensen *et al.*, 2007), and is not repeated here. Climate change projections based on model output for the East Africa region can readily be examined at country and regional scales through the use of online display tools such as Climate Wizard² and the United Nations Development Program Climate Change Country Profile website at Oxford University (McSweeney *et al.*, 2010: available online at³). In this section we discuss results of these model projections and new research results of relevance to the Great Lakes Region.

5.3.1 Recent improvements in climate modeling

Central to scientific investigation on climate change are ever more comprehensive and sophisticated environmental modeling efforts performed both according to organized protocols, such as the multi-model framework utilized most recently in the IPCC Fourth Assessment Report (IPCC, 2007), and also by many globally distributed organizations working more independently. Results compiled by the IPCC indicate that the global mean temperature response to a doubling of atmospheric carbon dioxide would be an increase of about 3°C, and at current rates of emissions, this mark would be surpassed across East Africa before the end of the 21st century. Precipitation is also projected to increase significantly across the region, with gains of 20% or more forecast for the northern part of the region by the end of the century (Figure 5.8).

¹ www.ipcc.ch/publications_and_data/ar4/wg2/en/ch9.html

² www.climatewizard.org

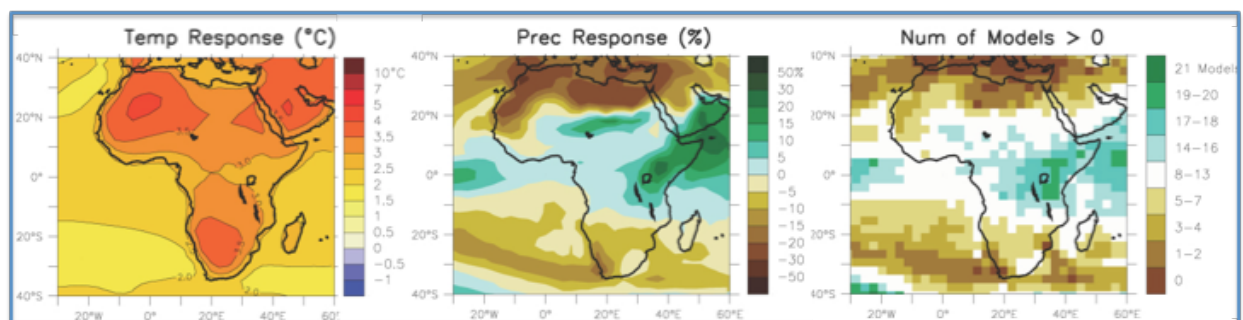
³ www.geog.ox.ac.uk/research/climate/projects/undp-cp/

New results for the fifth phase of the Coupled Model Intercomparison Project (CMIP5) are becoming available as of this writing; the CMIP5 model simulation will provide the basis for the predictive component of the forthcoming IPCC Fifth Assessment Report, due for release in September 2013. These simulations are being based on a set of four global emissions projections, the Recommended Concentration Pathways (RCPs), which replace the emissions scenarios used in the IPCC 2007 assessment (van Vuuren *et al.*, 2011). For this review we emphasize new climatological projections for the 21st century focused on continental Africa from the CCSM4 model as recently published in Meehl *et al.* (2011). The models utilized in the IPCC Fourth Assessment evaluations already showed convergence towards common solutions for eastern Africa, which adds to building confidence that global climate model projections are valid guidance for regional planning for climate change. The new results from the CCSM4 appear to be largely consistent with the earlier projections.

A common problem encountered when working with climate model output for many regions of Africa is a lack of baseline data needed to ensure that models are launched with proper representation of actual conditions as a starting point. Instead, interpolation techniques must be applied between widely separated data points, greatly smoothing out local climatic detail – the detail that determines many characteristics and particularities of local ecology. This insufficient representation is especially problematic in mountains, around large water bodies and other regions of complex topography, where both climatic and related ecological gradients are especially large. This is largely the case for much of the Great Lakes Region, where complex landscape configurations and widespread absence of verifiable point data resulting from sparse and poorly sustained climatological observations stand as obstacles to efforts to apply models for predicting climatic and ecological futures. With the rapid improvements in environmental modeling and the addition of more years and improved spatial coverage of data inputs to the new sets of simulations, the new CMIP5 simulations should offer provide major improvements over the results previously available.

Figure 5.8 Multimodel consensus products for temperature and precipitation from the IPCC (2007) assessment report

Temperature and precipitation changes over Africa from the Multi-model Dataset simulations run under the A1B greenhouse gas emissions scenario, a projection of rapid economic growth with a stabilizing human population, as presented in the 2007 IPCC Fourth Assessment Report. **(Left)** Annual mean temperature change between 1980 to 1999 and 2080 to 2099 averaged over 21 models. **(Middle)** Same as left, but for fractional change in precipitation. **(Right)** Number of models out of 21 that project increases in precipitation. These and related results represent the consensus of modeling efforts conducted in the first years of the 21st century, and suggest fairly strong agreement among models on the principal climatic changes across East Africa at broad scales. Source: modified from Figure 11.2 of the IPCC Fourth Assessment Working Group One Report (Christensen *et al.*, 2007)

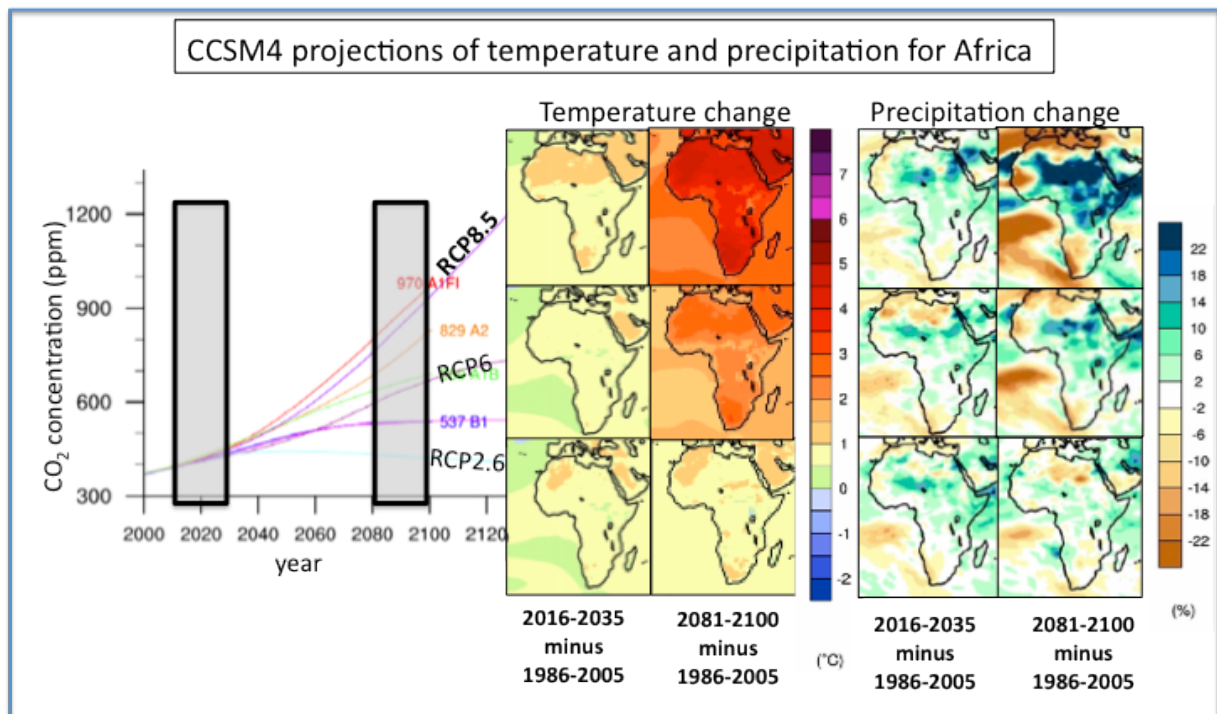


5.3.2 Projections for temperature

In common with model projections for all continental landmasses, East Africa is forecast to continue the currently observed warming trend unabated through the course of the 21st century, and likely beyond. While inter-annual variability over the region will continue to be dictated by external forcings from coupled atmosphere-ocean phenomena such as ENSO and the IOD, the secular thermal increase forced by greenhouse gas emissions seems inexorable. And, barring unforeseeable events such as temporary global cooling yielded by large injections of volcanic dust to the stratosphere, the warming will be irreversible for many decades to come (Solomon *et al.*, 2009). For the Great Lakes Region, the major questions related to future temperatures are the rates of warming of the atmosphere and water bodies, and the associated consequences to human and natural systems. The new CCSM4 results for Africa are consistent with the previous IPCC multi-model means, with the magnitude of warming being proportional to the modeled levels of anthropogenic emissions (Meehl *et al.*, 2011) (Figure 5.9). A broader global view (not shown) of the CCSM4 results for 21st century temperature show that the projected warming in tropical Africa, while of serious concern given its magnitude, is actually among the lowest projected over continental areas worldwide.

Figure 5.9 New climate model projections for Africa.

Model output has recently become available from some of the new simulations that will be evaluated in the forthcoming IPCC Fifth Assessment Report (expected in 2013). Shown here are mapped projections of temperature ($^{\circ}\text{C}$) and precipitation (%) changes for Africa from simulations of the CCSM4 model for 20-year periods centered on 2025 and 2090 compared to baseline conditions centered on 1995. The graph on the left side of the figure shows modeled carbon dioxide concentrations according to past SRES and new Representative Concentration Pathway (RCP) emissions trajectories. The shaded boxes indicate the two time periods covered by the plotted data. The maps show in rows, from top to bottom, temperature and precipitation changes under RCP8.5, RCP6 and RCP2.6. Modified from material presented in Meehl *et al.* (2011).



5.3.3 Projections for rainfall

As indicated in figure 5.8, there is a strong model consensus that precipitation will increase significant over the course of the 21st century in direct response to anthropogenic warming of the global atmosphere. Taken collectively, the models indicate more intense wet seasons, increased intensity of high rainfall events and for less severe droughts (Shongwe *et al.*, 2011), but significant increases are not projected to begin for several decades. Significant seasonality changes are evident in model results focused on the Albertine Rift in the Lake Tanganyika and Malawi/Niassa/Nyasa basins, which project most of the annual rainfall increase to occur as a lengthening of the end of year Short Rains (Seimon and Picton Phillipps, 2012). New CCSM4 model results appear to be broadly consistent with the IPCC (2007) multimodel projections (refer to Figure 5.9). Such rainfall increases hold the potential to moderate hydrological stresses from intensifying evaporation that will attend the warming trend, but only after a multidecadal period of increasing hydrological drying as warming temperatures intensify evaporative

losses. A dissenting view challenging the value of these model-derived assertions of a wetter future East Africa was presented by Funk *et al.* (2008), who assert that empirical evidence linking warming of the central Indian Ocean to rainfall decreases near the East African coast implies a drier future for the region. The trend for decreasing rainfall during the Long Rains season over the past decade across East Africa identified by Lyon and DeWitt (2012) is a possible indication of a developing conflict between model projections and observations, though this may yet prove to be a temporary trend associated with oceanic variability.

To summarize, the key aspects of the consensus scenario developed from multiple model simulations of evolving future climatic states across the Great Lakes are as follows:

- The current secular trend of temperatures increase will continue throughout the 21st century at a rate of approximately one third of a degree Celsius per decade;
- Total annual precipitation will increase markedly across much if not all of the region by the end of the century, in the range of 15-20%, although the positive trend may not become established for several more decades;
- Hydrological stress will initially intensify under the warmer and more variable climate before alleviation from large precipitation increases after several decades;
- Precipitation intensity will increase as temperatures increase according to the exponential increase in the atmosphere's water vapor carrying capacity as a function of temperature;
- Precipitation seasonality will shift, especially in the southern basins, with pronounced increases in late-year rainfall;
- As demonstrated in the previous section, teleconnected forcings such as ENSO and the IOD drive East African climatic variability, and that these forcings are therefore likely to be key agents in how climate change will affect present day climatic patterns and shape environmental, sociological and ecological changes across the region.

Some very important caveats apply when considering the potential impacts of such climatic changes. While it is very encouraging that the new generation of models appears to be validating the consensus view put forth in the most recent 2007 IPCC report, it must be remembered that such model predictions are effectively experiments whose predictive accuracy cannot be verified for many years to come. Additional uncertainties arise from the potential impacts of anthropogenically driven LULC changes in the region, which are certain to be large in scale. However, in the absence of compelling reasons to refute these projections, developing planning frameworks around them appears to be a sensible course of action. In addition, we need to look at direct and indirect impacts of climate change, and abrupt and long-term impacts, on species, ecosystems, ecological processes and services, and not simply focus on long-term direct climate change.

Another issue that is especially problematic to interests concerned with biodiversity conservation is that climate model output is expressed in terms of changes in climatic parameters, primarily temperature, precipitation and cloud cover that are difficult to translate directly into ecological outcomes. The utilization of dynamic vegetation models and other models that project changes in ecological parameters based on the changing climatic parameters offer conservation planners much more diverse and potentially useful outputs. Although these models have been criticized for being ecologically and

statistically naive (ignoring biotic interactions, adaptive evolution, dispersal limitation, and historical chance), and their application has been questioned for taxa other than plants (Beale *et al.*, 2008), a recent meta-analysis reveals that changes in species distributions have consistently tracked temperature changes over the last few decades of anthropogenic global warming (Chen *et al.*, 2011). Within the East African Region, the use of the Lund-Potsdam-Jena (LPJ) dynamic vegetation model (Sitch *et al.*, 2003) has been demonstrated broadly (Doherty *et al.*, 2009, 2010) and at more focused scales in the Albertine Rift (Picton Phillips and Seimon, 2009). Among the parameters generated as standard output from LPJ simulations are net primary production, hydrological runoff, evapotranspiration, a fire frequency indicator, carbon fluxes of vegetation and soils and plant functional types; several of these are discussed further in section 3. Similar comprehensive suites of outputs are now being generated directly from atmospheric models in coupled Earth System Models of Intermediate Complexity (EMICs) (Weber, 2010). The application of these new tools in biodiversity conservation vulnerability and adaptive planning initiatives in tropical Africa is likely to increase as the diverse sets of data products become available, and in time, may largely obviate the need for many specialized modeling exercises tailored to particular landscape or purposes.

5.4 Critical issues for biodiversity and Ecosystem Services

5.4.1 Adapting conservation practice and natural resource management

In this section, possible climate change impacts on biodiversity and Ecosystem Services across the Great Lakes Region are explored. The growing confidence in climate projections and relatively high degree of consistency among the various models supports the development of proactive approaches to conserve biodiversity and safeguard Ecosystem Services important for human livelihoods. Across tropical Africa, the conservation and development communities have begun to actively incorporate climate change projections into vulnerability assessments of species, ecosystems, and Ecosystem Services (Gray, 2011; Belfiore, 2011; McClanahan *et al.*, 2009). However, a recent review (Seimon *et al.*, 2011) has shown that the effective implementation of the adaptation strategies that come from these vulnerability assessments is often hindered by a lack of comprehensive knowledge of the role of climatic variability in the social or ecological system of interest, and of its vulnerabilities related to climatic factors. Comprehensive climatic assessments cannot be determined by relatively superficial methodologies based on projections of temperature and precipitation changes alone, but should include how changing the climatic conditions will drive changes in vegetation, hydrology, and ecosystem functioning and human responses to such changes. The complexity of climate change – along with the inherent uncertainties associated with prediction of future climatic states – make comprehensive evaluation of risk and opportunities especially challenging.

Major climate anomalies are significant stressors to social and ecological systems. For example, the spate of recent droughts in the Greater Horn of Africa, culminating in the near total collapse of food production across a broad region in 2011, have affected a region with a low-coping capacity causing a broad cascade of negative outcomes (Lyon and DeWitt, 2012). Conversely, the excessive rainfall early in 1997-98, when strong sea

surface temperature anomalies in the Pacific and Indian Oceans coincided, created widespread flooding and rapid increases in lake levels across East Africa (Anyamba *et al.*, 2002; Conway *et al.*, 2005). The lack of precedence for guiding future actions is further evident in modeling results that project local combinations of temperature and precipitation patterns in coming decades that are not known to exist anywhere in our past human experience, giving rise to new descriptors such as *novel climates*, and their ecological counterparts, *no-analog communities* (Williams *et al.*, 2007; Williams and Jackson, 2007).

For such reasons, it is clear that there is still much to learn before sufficient assessments of the potential impacts of climate change on biodiversity and Ecosystem Services across the Great Lakes Region can be completed. To fill some of these knowledge gaps, inventories of species and their distributions, and of Ecosystem Services and their utilization by human populations, are being undertaken for much of the region (Plumptre *et al.*, 2007; Platts *et al.*, 2010; see also chapters 2 and 4 in this report). A broad review of the literature shows that, generally, there are many possible ways climate change will impact biodiversity and Ecosystem Services (Table 1). These impacts can be divided into discrete *acute impacts*, principally extreme weather related events (e.g., storms, droughts, fires, extreme rainfall events), and continuous *chronic impacts*, such as gradual increases in mean temperatures or decreases in seasonal rainfall, occurring over decades. The interactions and consequences of climate change on biodiversity are multidimensional and defy simple two-dimensional illustrations although it is possible to represent some of the likely impacts on terrestrial and freshwater systems (Figure 5.10; refer also to Table 5.1).

There is some uncertainty about even the gradual chronic impacts, as possibilities exist for abrupt climate shifts that can act alone or with chronic stressors to push an ecosystem beyond a threshold and into another state. For example, the desertification of former grasslands that once covered much of the Sahara is believed to have been a tipping-point response to slow orbital forcings that crossed a critical threshold approximately 5,500 years ago (Gasse, 2000). Similarly, although the Holocene has seen only minor shifts in orbital forcing, the paleo record for East Africa indicates that high amplitude changes have nonetheless occurred, causing major shifts in lake stands and other environmental responses.

Table 5.1 General potential impacts of climate change on terrestrial and freshwater environments (adapted from Kingsford and Watson, 2011)

Biome	Component of environmental change	Potential Impacts on biodiversity and Ecosystem Services
Terrestrial	Increased rainfall and intensity of storms	Increased fuel loads from enhanced wet season rainfall will increase fire risk in following dry seasons
		Destruction of natural vegetation cover, agriculture and concomitant reduction in carbon stocks
	Increased droughts	Physiological tolerances are exceeded and selection is for species adapted to dry environments

		Increase in fire events may result in an increase in fire-dispersed species or fire adapted species (e.g. more grasslands and invasive species)
	Increased rainfall variability	Selection for species that are able to cope with wide ranges in precipitation; species with narrow climate envelopes may become threatened. Increased crop pest problems, especially from migratory pests, as a result of breakdowns in biocontrol after sudden widespread rains following severe dry seasons and droughts
	Rising temperature	Range shifts in biota where physiological tolerances to temperature are exceeded. Species requiring cooler temperatures may shift towards higher elevations, if possible. Some loss of high elevation species (the “summit trap” phenomenon)
	Increases in extreme temperatures	Temperature extremes may exceed biotic tolerances for some species leading to population crashes for some species.
	Increased fire (frequency and intensity)	Promoted by altered vegetation communities (e.g. more grasslands and invasive species). Hotter fires already responsible for mass mortality (e.g. rainforests)
	Alteration in the drivers that causes seasonality	Altered phenology and migration patterns for different organisms and potential decoupling of key biotic interactions (trophic linkages, pollination, seed dispersal)
	Increased carbon dioxide	Increased productivity of some vegetation but probably limited by other factors (e.g. nutrient, moisture). Woody plant encroachment in grasslands.
	Inundation of terrestrial communities via increased storms	Loss of some terrestrial communities, intolerant of inundation and/or increasing salinity
Freshwater	Reduced rainfall intensity, changed seasonality, reduced run-off and reduced flow	Aquatic biota will decline and perhaps shift their distributions.
		Spread of invasives species
	Increased rainfall	Increased erosion and sedimentation on steep and de-vegetated slopes, reducing depth of estuarine and freshwater habitats and affecting inundation duration; and high loads of sediment can negatively impact aquatic species
		Decline in wetland plants reducing propagules, and carbon stocks
	Increased water temperature	Increased temperature potentially beyond tolerances of freshwater biota, favoring generalists or invasive over native species
		Increased eutrophication and algal blooms in inland lakes

5.4.2 Species vulnerabilities related to climate change

Understanding the impact of human-forced climate change on species requires examining earth’s history and future projections, based on understanding the drivers of climate change (Mackey *et al.*, 2008; Watson *et al.*, 2011). The paleo record shows that the Great Lakes Region has experienced momentous climatic shifts throughout the past several hundred thousand years, that vegetation transitions have been recurrent, and, during the cool and arid states that characterized global glacial epochs in East Africa, that afromontane vegetation was the dominant landcover (Jolly and Haxeltine, 1997; Elenga *et al.*, 2000; Marchant *et al.*, 2006; Cohen *et al.*, 2007). However, anthropogenic greenhouse gas emissions are now extending Holocene warmth towards unprecedented levels in million-year historical contexts, with warming rates also beyond known experience. Species are currently being exposed to climate change at a rate and

magnitude never previously experienced, with direct consequences for species assemblages and community composition (Watson *et al.*, 2011). It is believed that some climate patterns are already affecting migration patterns of species of birds (Beaumont *et al.*, 2006). Changes in bird species' distributions are predicted for tropical Africa as climate change intensifies during the course of the century (Hole *et al.*, 2009).

Terrestrial ecosystems are projected to significantly change as a result of these effects, with inevitable changes for the organisms that comprise them. Results from efforts to model the response of African flora and fauna to projected climatic conditions indicate substantial range shifts (e.g. McClean *et al.*, 2005; Simmons *et al.*, 2005; Garcia *et al.*, 2011), or, in the case of a study on mountain gorillas, uncertainty over species vulnerability and response to climate change (Belfiore, 2010). For example, one study that examined temperature increases projected for the year 2100 over the Albertine Rift under elevated CO₂ scenarios suggest that thermally-sensitive species will have to extend their ranges upwards by 600-720 meters in order to track conditions that they are accustomed to (Seimon and Picton Phillipps, 2012). However, these models are often limited in that they are based only on factors associated with exposure climate change, and do not consider adaptive capacity or sensitivity to climate change (See Watson *et al.*, 2011 for a discussion of the problems associated with this). There is a need to look at species niches in more detail and use the results to model the impacts of climate change on these species as well as their habitats (see Figure 5.10). The influence of competition between species and the impacts of competitive release or alternatively increased competition that may come about under climate change will affect projections of species ranges under future climate scenarios. A review of the literature of the impacts of climate change on species and ecosystems shows there is a dearth of studies, and much more research is needed to understand the impacts outlined in Table 1 and Fig. 10. Changes in rainfall and temperature will affect ecological processes such as growth, flowering, germination and recruitment, yet we do not have a complete understanding of how this will affect the flora of the Great Lakes. Key abiotic characteristics, the basic building blocks of a species' fundamental niche (e.g. temperature, rainfall, cloud formation, rates of evapotranspiration, etc) will change and affect distribution and abundance of many species in unknown ways. Some of the impacts are better known than others, including alterations to the length of the growing season, changes to the timing of seasonal events (e.g. phenology), and stratification period in lakes (Parmesan and Yohe, 2003; Root *et al.*, 2006) but these impacts of climate change are hard to predict, requiring detailed knowledge of a species' ecology (Whittaker *et al.*, 2005).

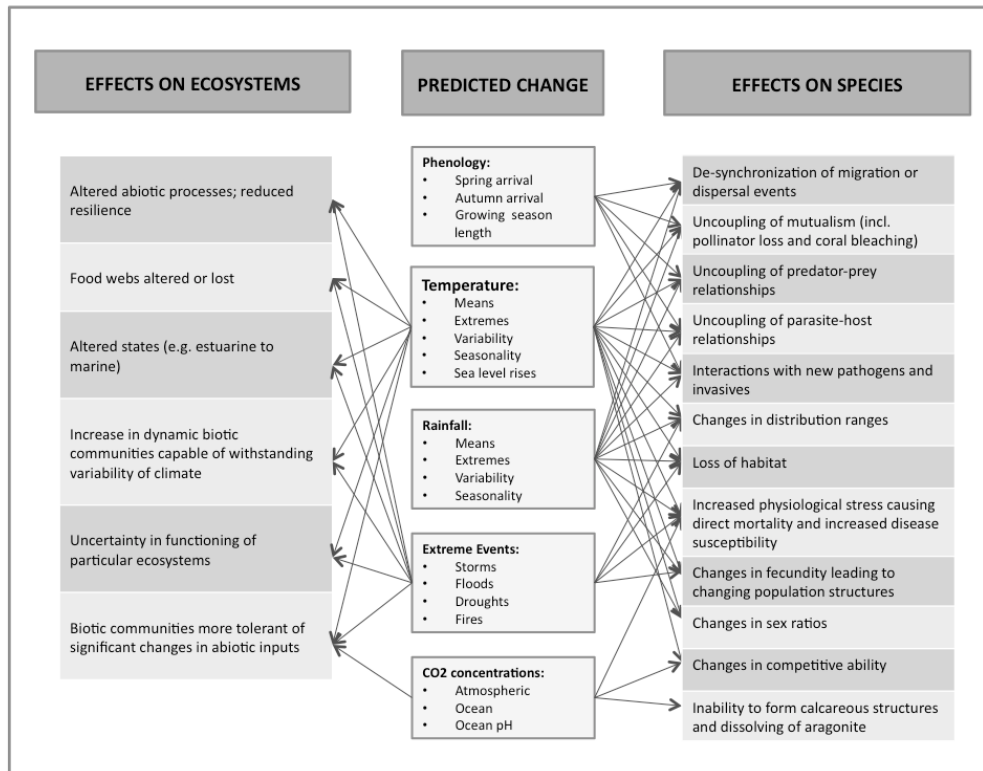
5.4.3 Understanding impacts on Ecosystem Services

Because of the numerous ways that both species and ecosystems can be impacted by climate change, it is clear that the stocks and flows of Ecosystem Services will vary considerably with climate change, although the magnitude, rate and direction of changes are uncertain. Furthermore, the rapidly increasing human populations across much of the Great Lakes Region already place considerable stress upon many Ecosystem Services. The synergistic effects of combined threats complicate understandings of how Ecosystem Services will respond to climate change and other stressors. Few Ecosystem Services respond linearly to change (Barbier *et al.* 2009), so, models that can handle complexity will be needed for predictive purposes. It is beyond this chapter to assess the impacts of

climate change on all the Ecosystem Services outlined in chapter 4, but below we provide some examples of how tools such as dynamic vegetation models can provide guidance for conservation planning.

Figure 5.10 Climate change impacts and their predicted effects on species

(Source: Kingsford and Watson, 2011, adapted from Foden *et al.*, 2009).



5.4.4 Predicting future ecological conditions

The products generated by dynamic vegetation models and crop models offer potential to provide projections of changes to biophysical parameters underlying Key Ecosystem Services across space and time. The projected warming and wetting of East African climates in coming decades is likely to have a multitude of effects, both of positive and negative consequences to biodiversity and humanity. While many negative impacts are to be expected, there are also indications that some changes may benefit certain species and humanity. Modeled vegetation response to projected climate changes across East Africa using the LPJ dynamic vegetation model indicate substantial increases in tropical woody vegetation in grassland regions, large increases in net primary productivity (18-36%) and total carbon storage (3-13%) (Doherty *et al.*, 2010). Such shifts could increase the availability of some Ecosystem Services, such as fuel provisioning and climate regulation, but may reduce access to other services, such as those provided by grasslands for grazing livestock, which may currently be important for local livelihoods. The Wildlife Conservation Society's (WCS) Albertine Rift Climate Assessment Project, funded by the MacArthur Foundation, has generated a broad suite of products using the LPJ model and projections of changes in agricultural yields from crop models (Picton Phillipps and Seimon, 2009). Examples are offered below of how these products can provide guidance on the ways in which climate change will affect Key Ecosystem Services. In these examples, the model inputs are gridpoint means of temperature, precipitation and cloud cover averaged from a collection of climate models run under the

A2 emissions scenario and downscaled to 0.5° (~60 km) spatial resolution. As discussed in the sections above, the 21st century climate across the Albertine Rift region is characterized by rapid warming, with a net predicted change of 3.6°C by 2100, attended by an initially slow but then rapid increase in rainfall as the century progresses (Seimon and Picton Phillipps, 2012). However, it must be noted that these models do not take into account landuse change.

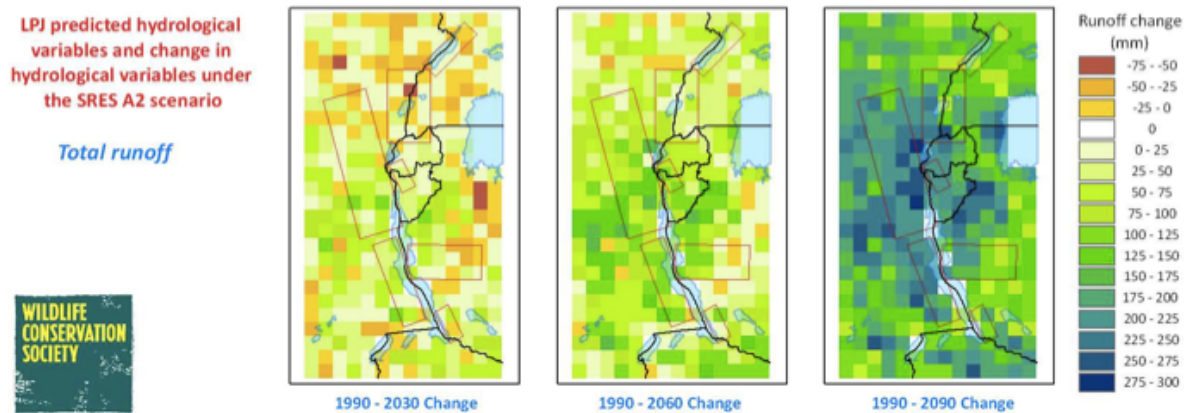
a) Water: Total Runoff projections and the impacts on water resources important for Ecosystem Services

The potential impacts of climate change on freshwater ecosystems are of major concern for the Great Lakes Region. There are already considerable pressures on the freshwater ecosystems from diversion of water (Vörösmarty *et al.*, 2010) and climate change is likely to further impact freshwater ecosystems, particularly those already affected by river diversions and water resource development (Avery, 2010; Kingsford, 2011). Increasing water scarcity combined with increasing human populations will mean that more freshwater ecosystems are likely to be exploited for satisfying basic human needs such as hygiene, cooking, and drinking water. There will also be considerable pressure on water resource exploitation for agricultural production within the region to meet food markets that depend on irrigation development. However, making specific predictions about the nature of future changes in water supply in different locations throughout the region is complicated by the fact that studies from a variety of basins in Africa indicate that water supply will change non-linearly with changes in precipitation (de Wit and Stankiewicz, 2006).

The LPJ product for hydrological runoff offers improvements over products derived from climate models alone since LPJ incorporates additional factors such as water uptake by vegetation, soil percolation, evapotranspiration and CO₂ fertilization effects on vegetation as greenhouse gas buildup proceeds over time. For the Albertine Rift study we plotted annual runoff changes for the years 2030, 2060 and 2090 relative to a baseline set in 1990 (Figure 5.11). These results suggest a nonlinear runoff response (from steadily increasing greenhouse gas) increases with considerable spatial variability. Initially, runoff reductions are shown across large areas of the modeled region with other regions experiencing minor increases. By 2060 light to moderate increases dominate, and by 2090 moderate to very large increases in runoff are shown for the entire domain. Such changes would have considerable impacts on hydrological processes, and fresh water ecology, among other things. The results also demonstrate that changes in climatic conditions forced by steadily increasing greenhouse gases could yield widely differing outcomes across space, even in adjacent landscapes. The focused Albertine Rift results are similar to broader regional results for an East African domain encompassing the Great Lakes Region, where total runoff increases averaging 19% relative to baseline means is projected for the end of the century under the A2 emissions scenario (Doherty *et al.*, 2010).

Figure 5.11 Total runoff changes in the Albertine Rift

Projected changes in hydrological runoff for the Albertine Rift corridor generated by the Lund-Potsdam-Jena (LPJ) dynamic vegetation model run with downscaled multi-model inputs. Source: WCS Albertine Rift Climate Assessment (all products available at www.albertinerift.org/Challenges/ClimateChange/tabid/7525/Default.aspx)



Among impacts that might be experienced by such changes in runoff are the following:

- **Wetland ecosystems.** Freshwater wetlands are of critical importance to biodiversity and many human communities. The initial reduction in runoff might indicate increased potential for desiccation of wetlands; conversely, the excessive runoff projected throughout the Albertine Rift in the latter part of the century would introduce the potential for inundation of many key wetlands, and markedly changed hydrology, sediment loads and nutrient transport that could, in turn, greatly affect fish populations, tourism potential, and other services that wetlands provide.
- **Lakes and rivers.** Given the high sensitivity of East Africa lake levels to climatic perturbation, the results suggest that a multidecadal period of falling lake levels is underway that should reverse by mid-century, with large and rapid rises occurring thereafter that may exceed levels observed in recent experience. Critically needed are investigations into how the individual great lakes, major rivers and other water bodies will respond. In particular, these runoff projections pose potential challenges to hydropower generation, which could have major impacts on national economies and human development. Initial reductions in lake levels and river flows could reduce generation potential, whereas the excessive runoff projected later in the century may overwhelm existing facilities or require reestablishment at new sites. Climate change means that planning for new hydropower generation projects throughout the Great Lakes Region (e.g. Rusumo Falls Dam on the border of Rwanda and Tanzania; Gibe III Dam on Omo River in Ethiopia, or Rusizi III Dam between Rwanda and DR-Congo) must take into account the strong potential for climate change to cause significant differences in water flows when compared to current conditions.

The implications of these projected runoff changes for Ecosystem Services such as food production from fisheries and agriculture, and energy production, for example, are critical

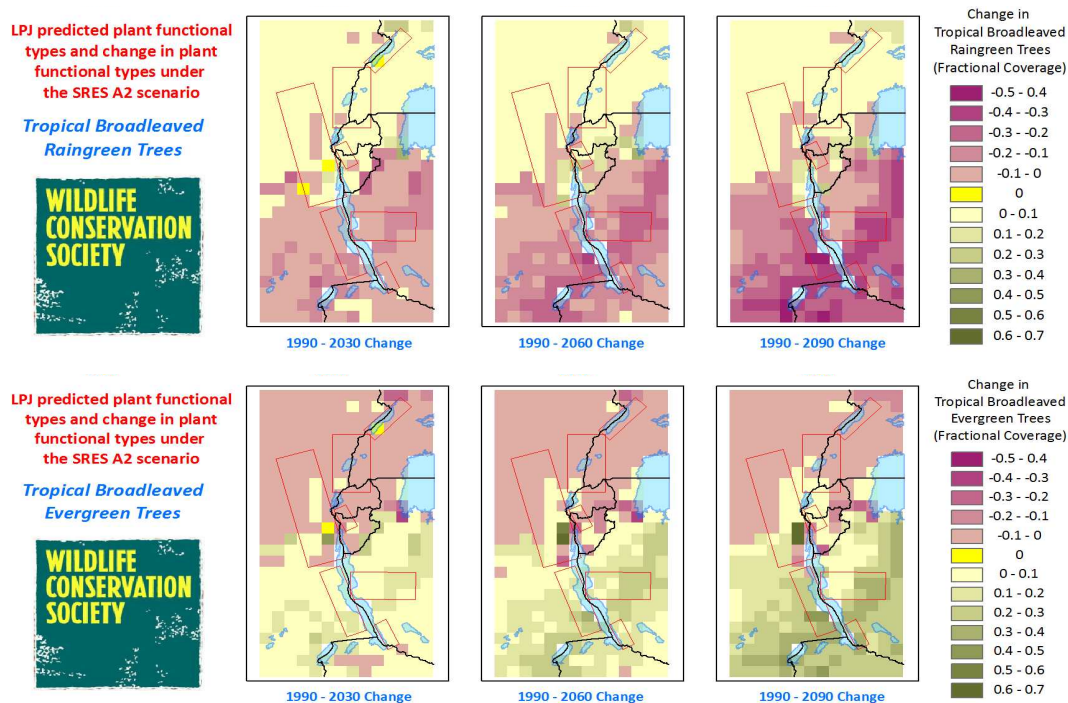
areas for further investigation. There are important caveats that apply when interpreting such results. The spatial resolution shown, while improved over climate model output, is still very coarse relative to the scales of most ecological processes and human activities. Furthermore, the runoff product references potential vegetation distributions according to climatic conditions rather than actual landcover. The compounding effects of human extraction and diversions of water and land use/land cover change will all act synergistically with the climate-driven changes to create runoff patterns that might differ considerably from those driven by climate changes alone.

b) Vegetation response: projections on forest changes and resultant impacts on Ecosystem Services

The LPJ model generates a variety of products related to vegetation changes projected to occur in response to climate change and the buildup of atmospheric CO₂. It is limited in that it only examines elements associated with exposure to climate change and does not consider sensitivity, adaptive capacity and human land use. However, it offers considerable insights into processes that cannot be determined through climate models alone. For example, across East Africa, LPJ simulations run under inputs from a range of climate models all show substantial replacement of grasslands by woody vegetation by the end of the century (Doherty *et al.*, 2010). In the Albertine Rift, the models show a major transition in Plant Functional Type (PFT) projected for the southern half of the domain. The currently dominant deciduous forest (PFT class: “Tropical Broadleaved Raingreen Trees”) is projected to decline in coverage and be replaced by evergreen rainforest (PFT class: “Tropical Broadleaved Evergreen Trees”) currently dominant only in the northern part of the Rift region (Figure 5.12).

Figure 5.12 Explicit model projection of a major vegetation change from climate change

Changes in Plant Functional Type (PFT) predicted by the LPJ model run using multi-model climate output under the A2 greenhouse gas emissions scenario over the Albertine Rift region for two dominant classes in tropical Africa. Shown are changes in fractional coverage (range from -1.0 to 1.0) for PFT classes *Tropical Broadleaved Raingreen Trees* (top row) and *Tropical Broadleaved Evergreen Trees* (bottom row) for the years 2030, 2060 and 2090 relative to baseline conditions in 1990. These results indicate a process of replacement of predominantly deciduous vegetation by evergreen forests during the course of the century across the southern half of the region encompassing the Lake Tanganyika basin. Data is from the WCS Albertine Rift Climate Assessment.



Such changes have widespread implications for biodiversity and Ecosystem Services as greenhouse gas forcing may promote important redistributions of vegetation. Such implications include:

- Changes in climate regulation through carbon storage and sequestration:** Forest composition changes are likely along with changes in Net Primary Production (NPP), and may affect standing carbon stocks and the carbon sequestration potential of the landscapes. However, data on NPP is severely limited for Africa, complicating efforts to predict these changes (Malhi *et al.*, 2011).
- Changes in timber products and non-timber forest products (NTFPs):** Changes in forest composition could impact livelihood practices and enterprises currently tied to specific forest species found in deciduous forests. Shifts from deciduous forests to evergreen forests could affect species used for fuelwood, construction materials, medicinal uses of forests, and food. In some cases, species used for purposes, such as fuelwood, may be more substitutable than species used for medicinal purposes, for example (Brown *et al.*, 2011).
- Hydrological Cycling:** Evergreen versus deciduous trees may have different water and nutrient budgets, so, these shifts may impact water availability at different points in the year (see Asbjornsen *et al.*, 2011).
- Dispersal/pollination:** Changes in floral composition will likely influence populations of dispersers and/or pollinators that may be very important for honey, wild foods, crops and for forest functioning in general (Kj hl *et al.*, 2011; Munyuli, 2011). In addition, species that play critical roles in dispersal and pollination may be directly affected by climate change, as discussed previously.

Many of the same caveats outlined above apply in this context as well particularly with regard to the model's land surface characterization that does not incorporate actual land surface patterns, which for a considerable part of the Albertine Rift region is heavily modified by human activities. Also, there is evidence that increased carbon dioxide levels from anthropogenic emissions favor woody plant growth (Ainsworth and Long, 2005) and may promote conversions of grassland savannahs to scrublands in Africa (Bond *et al.*, 2003). Furthermore, other changes may be occurring independently or synergistically, such as the proliferation of invasive species such as *Lantana camara*, an ornamental bush introduced to East Africa, across savannah ecosystems (Plumptre *et al.*, 2010). These changes could influence the availability of Ecosystem Services such as fuelwood, fibers, medicine, food, pollination, and water regulation services.

c) Changes in food production

In common with much of the Great Lakes Region, human populations of the Albertine Rift are dependent upon subsistence agriculture for sustaining livelihoods and nutritional needs. The associated land use patterns, and conversion of wild lands for agricultural purposes to serve a growing population, are among the most serious threats to region's biodiversity (Plumptre, 2012). Furthermore, the regional dependence on rain-fed crops for cultivation and pastures for livestock grazing and related thermal tolerances of both crops and livestock creates high susceptibility for agricultural practices to be significantly affected by climate change. While coping with climate variability is certainly not a new problem for African farmers, existing coping mechanisms may be overwhelmed by the challenges that are likely to emerge as the climate changes in the future (Thornton *et al.*, 2009).

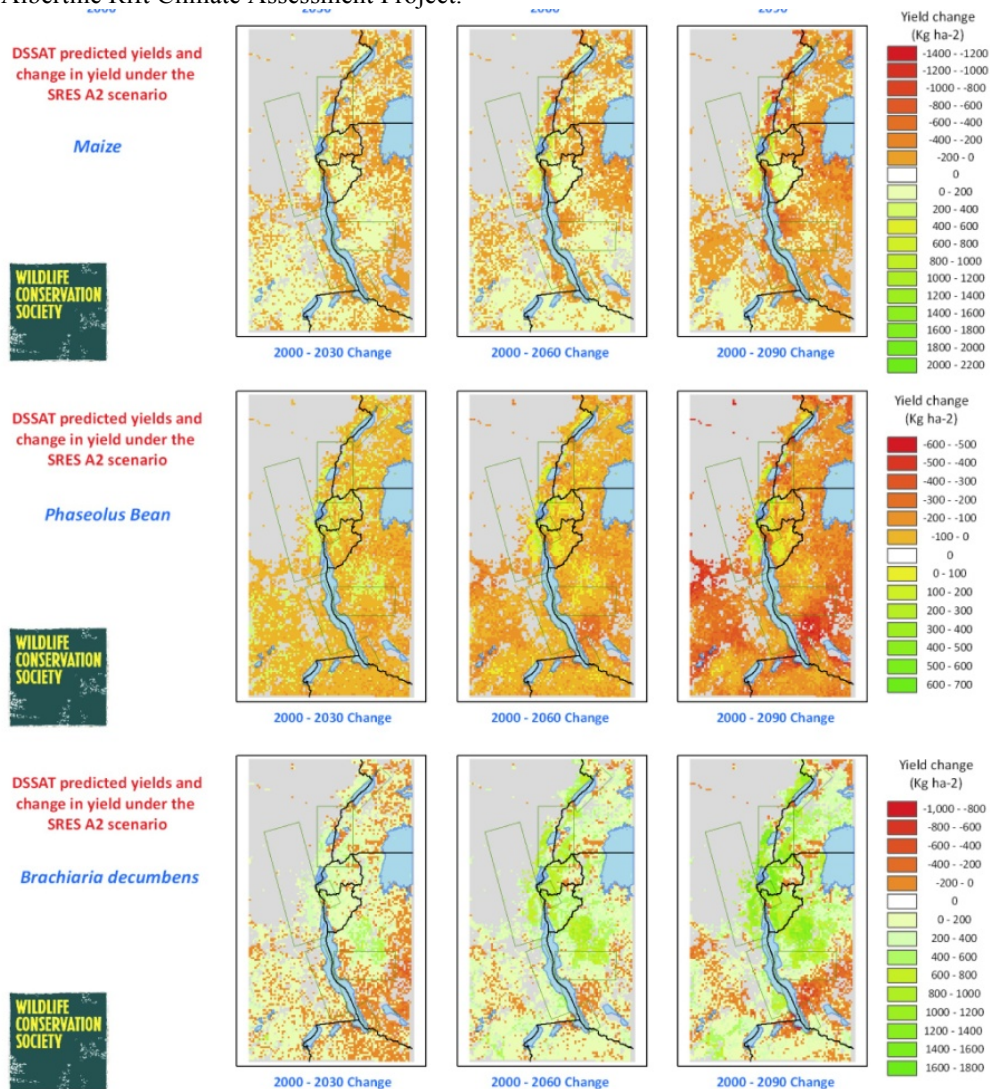
In consequence, there are likely to be substantial shifts in the patterns of African cropping and livestock keeping by the middle of the century (Jones and Thornton, 2009; Thornton *et al.*, 2009). Conditions in some regions of East Africa, particularly in the highlands, may promote yields increases of some key cultivars (Doherty *et al.*, 2010). However, model results run under severe warming of a 4-5°C increase show reductions in the length of growing period for all of southern Africa up to the Lake Malawi/Niassa/Nyasa basin by more than 20% relative to the present (Thornton *et al.*, 2011). The highland regions of Kenya and Tanzania are the only regions that show substantial gains (5-20%) in length of growing periods – a potential benefit to the region's human populations -- presumably from the strong increases in precipitation amount projected to accompany the warming. For the Albertine Rift, the WCS project utilized a crop yield model, the Decision Support System for Agrotechnology Transfer (DSSAT) (ICASA, 2007) to simulate the responses of two cultivars, maize and phaseolus beans, and a cultivated forage grass, *Brachiaria decumbens*, a species native to central and East Africa at altitudes ranging from 500 to 2,300 m above sea level, widely distributed and used as cattle feed (Figure 5.13). The DSSAT model results show high spatial variation, with well-defined patterns of gains and reductions in yield for maize, beans and *B. decumbens* by late in the century; these changes only relate to changes in potential yield across space, as they consider neither improvements in cultivation practices, such as anticipated widespread application of Green Revolution technologies, nor present-day land coverage of these cultivars and limiting factors such as soils.

Among possible consequences from climate change impacts on food provision and agriculture derived from these model results and other climate-related factors are the following:

- **Agricultural yield.** The model depicts substantial losses for maize and bean yields throughout the Albertine Rift as climatic conditions become increasingly unfavorable by late in the century, with the exception of central parts of the domain (in Rwanda, Burundi and eastern DR-Congo), which are highly elevated and therefore cooler. These results suggests that replacement crops will become necessary over time to sustain food security in areas depending upon these and related cultivars.
- **Livelihoods and nutrition.** The results for maize and beans contrasts greatly with the projections for *B. decumbens*, which benefits significantly under the warming and moistening climates registered in yield increases of more than 1,000 kg ha⁻¹ across large parts of the region, although significant reductions in yield are also registered in some areas, most notably across the southeast and southwestern parts of the Rift region. The changes for *B. decumbens* are directly related to livestock carrying capacity, and, taken at face value, imply that livelihoods based around livestock rearing will become increasingly attractive as cultivation becomes increasingly challenged by climate change. Expansion of pastoral activities may be hindered, however, by the replacement of grasslands by woody scrublands (Doherty *et al.*, 2010).

Figure 5.13 Examples of dynamic vegetation modeling of agriculture

Albertine Rift region yield changes (kg per hectare) of maize, phaseolus beans and the pasture grass *Brachiaria decumbens* between the years 2000 and 2090 under the SRES A2 emissions scenario. Source: WCS Albertine Rift Climate Assessment Project.



- **Wildlands conversion to farmland.** The building stresses upon cultivation appear to be maximized at lower elevation, particularly in the densely populated areas proximal to the region's great lakes. At the same time, highland areas currently occupied by some of the region's remaining stands of montane forest are shown to offer increasing potential for cultivation, which may exacerbate current pressures on these forests which are being converted to farmlands to feed a rapidly growing human population (Plumptre, 2012; Belfiore, 2010). This in turn has negative implications for iconic species such as the mountain gorilla, which is critical for tourism.
- **Fisheries.** Another major concern for food provisioning across the Great Lakes Region are the impacts of lake surface warming. As demonstrated from well-resolved observations in Lake Tanganyika and Lake

Malawi/Niassa/Nyasa, the differential warming rates between lake surface and deep waters promotes thermal stabilization, which reduces nutrient transport to the surface lowering overall productivity, and thus is expected to reduce the yields of fisheries (Verburg and Hecky, 2009; Tierney *et al.*, 2010), which are critical source of protein and income for communities living in and around the lakes (Gray, 2011).

5.5 Conclusions

The growing certainty over the seriousness of climate change threats in tropical Africa has prompted responses across a spectrum of interests in conservation and development. These concern both mitigation efforts to slow the rate of change through actions such as reducing greenhouse gas emitting practices like deforestation; and adaptation efforts to change existing practices and planning to produce more sustainable outcomes in the face of increasing climatic stress. This conservation strategy for the Great Lakes Region recognizes the high degree of importance for climate change to be an integral component of all work looking forward. Climate change and its impacts in eastern Africa are highly dynamic research arenas encompassed within a wide range of scientific disciplines. In preparing this chapter we have therefore made efforts to utilize the most recent reference material and original sources as much as possible rather than existing compilations. The most recent 2007 IPCC report remains a valid and useful compilation of findings, although the next report planned for publication in 2013 should offer considerable advances and refinements. The application of dynamic vegetation models in the Albertine Rift and elsewhere already demonstrates that highly informative products for conservation applications can be generated from climate model output but more is needed. Further improvements in climate and earth system modeling will provide the conservation and development communities with increasingly powerful tools, though effective conservation planning and management for climate change will require the merging of guidance developed from these tools with locally developed knowledge and understanding of site-specific contexts.

In this chapter, the review of past climate behavior places contemporary conditions in longer term perspective and provides a reference base for gauging the degree of anomaly of predicted climate changes. Contemporary climatology and climate trends show how linked atmospheric-oceanic circulations are the principal drivers of climatic variability in East Africa. The examination of future climate identifies that a relatively consistent and coherent set of predictions of multi-decadal changes has emerged in model simulations that project a much warmer and wetter future for East Africa. Species and ecological systems across the region have experienced - and survived - large climate changes before. However, the rate of current change, and the magnitude of changes predicted have not been experienced for millions of years. Furthermore, climate change is occurring against a backdrop of other profound changes driven by human activity across the Africa.

The advances in climatological knowledge have been significant, but much remains to be resolved. One particularly important issue that still needs to be clarified by the climate research community is the strong trend for decreasing rainfall in the March-May Long

Rains season that appears to stand in opposition with climate model projections that call for increases in rainfall over time (Funk *et al.*, 2008). This downward trend relates to decade-scale variability influenced by Pacific Ocean sea surface temperature patterns (Lyon and DeWitt, 2012). This raises the possibility that reversal of the Pacific pattern, which could occur at any time, may act in concert with secular trends towards a wetter climate and cause an abrupt shift to sustained wet conditions and corresponding jump in lake stands and river flows to levels above recent experience.

The chapter has highlighted the limited knowledge on the potential impacts climate change will have on species, ecosystems, and ecological processes, which generate Ecosystem Services that are critically important for people living throughout the region. More research is needed to understand spatial and temporal distributions of biodiversity and Ecosystem Services, and how they may be impacted by climate change. This information then can be integrated into vulnerability assessments that will enable effective long-term planning. We need to move away from climate models that exclusively focus on exposure to climate change without incorporating other aspects of vulnerability, such as acclimation, interspecific interactions, dispersal limitations and adaptive capacity (Corlett, 2011; Dawson *et al.*, 2011; Rowland *et al.*, 2011). A process of assessing vulnerability by integrating mechanistic, empirical and observation methodologies is needed to provide more accurate adaptation options (Dawson *et al.*, 2011). Given both the uncertainty in projected future climates and the uncertainty inherent in most relevant ecological forecasting approaches, use of these models need to incorporate meaningful uncertainty (Watson *et al.*, 2011).

Based on the findings and discussion on climate change outlined in this chapter, we conclude by offering the following recommendations to those concerned with biodiversity conservation and the services it provides to humanity across the Great Lakes Region.

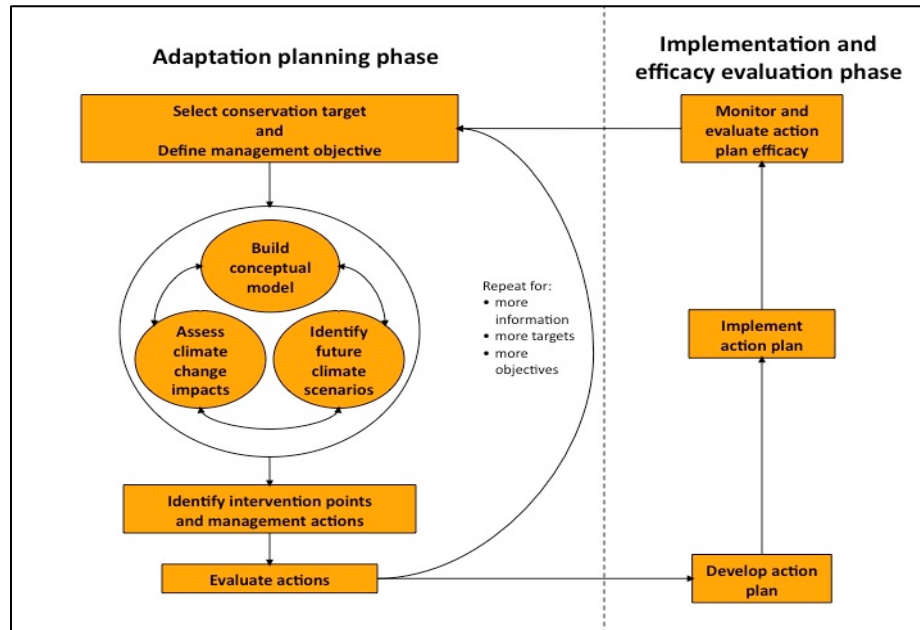
- ◆ **The need for integrating climate change in all forms of planning.** Given the strong evidence for human-intensified warming and model projections of further changes, it is now imperative that long-term conservation and development planning for the African Great Lakes Region incorporates projections of future states of the environment as it responds to climate change and humanity's responses to these changes. Conservation and development planners should identify potential climate change impacts in landscapes and sites of concern that are the direct consequence of climate changes as well as the indirect impacts that will be largely mediated through human response.
- ◆ **The need to understand all the components that human-forced climate change presents.** Conservation interests should recognize how climate change is a collective effect of different factors acting concurrently. We believe there are three broad components: the secular trends forced by the buildup of anthropogenic greenhouse gas emissions, changes in climatic variability caused by responses of external factors that influence East African climates, and the local effects of land cover changes related to human activity. To date most assessments only really consider the secular trends.

- ◆ **The need for basin scale climate change assessments.** The high spatial variability of climate across the Great Lakes Region, and distinct basin morphology, biogeography and hydrology of each of the major watersheds, point to the need for each basin to be assessed individually for its climate change sensitivity and response.
- ◆ **The need to understand the direct impacts climate change has on biodiversity and the biophysical environment.** There is a fundamental need to ascertain a baseline of how species, ecosystems, and ecological processes are currently affected by climate change to understand how Ecosystem Services will be affected by future changes. We also need to undertake forecast climatic conditions at high spatial resolution across the Great Lakes Region to serve conservation planning needs. These forecasts need to be robust in that they take into account exposure, adaptive capacity and sensitivity components. There is also a need to identify the tipping points of species, ecosystems, and ecological processes to stressors associated with climate change so that we can avoid crossing critical thresholds, beyond which it may be difficult and costly to restore or find substitutes for important Ecosystem Services.
- ◆ **The need to understand the indirect responses from human action.** There is a need to develop planning systems/mechanisms through tools that integrate climate scenarios and associated impacts on biodiversity and biophysical environments with anticipated human responses under different socioeconomic development and population trajectories.
- ◆ **The need to understand the response of other threats to climate change.** There is a need to improve understanding on how current threatening processes such as invasive species, mining, land use, diseases of humans, livestock and wildlife will change under different climate change forecasts.
- ◆ **The need to integrate monitoring into planning and vulnerability assessments.** There is a clear need to increase efforts to develop on the ground observations for species, ecosystems, and ecological processes and the Ecosystem Services they generate within KBAs and other areas of high conservation concern. However, these efforts need to be linked with a planning framework that allows this knowledge to lead to adaptive management. A good example of how monitoring can be integrated into a planning framework is outlined in Figure 5.14.
- ◆ **The need to test different adaptation solutions.** While it is clear that ensuring the resilience of populations of biodiversity and Ecosystem Services is an important objective to overcome the challenges climate change presents, we are still unsure which long term adaptation activities will work, and what the cultural, spatial and temporal dimensions are likely to affect this success. Across the Great Lakes Region, different adaptation activities are currently being considered, from fully protecting Key Ecosystem Services (e.g. those associated with watersheds) to managing off-reserve land for carbon or agriculture. Such activities will have trade-offs in terms of achieving their overall objectives and we need a platform to assess the array of possible adaptation activities that are currently being implemented or planned to be implemented, to work out what works and what does not.

- ◆ **The need to undertake ‘no regrets’ actions now.** The heavily fragmented landscapes today greatly limit such opportunities for the future, so ensuring connectivity among KBAs, especially those with longstanding protected area status such as national parks, should be seen as a critical ‘no regrets’ action. Connectivity along elevational gradients in mountainous terrain will be particularly important. Pressure on for conversion of wetlands and highland forests for cultivation and other purposes is also likely to increase as climate change intensifies over time. Both types of habitat are and will be critically important for sustaining biodiversity and also for ecosystem service provision. Protecting these habitats, particularly those identified as KBAs that currently lack formal protection status, should therefore be seen as priorities in contexts of climate change.

Figure 5.14 The Adaptation for Conservation Targets (ACT) framework

The structure of the Adaptation for Conservation Targets (ACT) framework as presented in Cross *et al.* (in review). An online description of this framework can be found at <http://www.cakex.org/virtual-library/2285>



References

1. Ainsworth, E.A. and S.P. Long, S.P., 2005: What have we learned from 15 years of free-air CO₂ enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO₂. *New Phytologist*, 165: 351–372
2. Alin, S.R. and A.S. Cohen, 2003: Lake-level history of Lake Tanganyika, East Africa, for the past 2500 years based on ostracode-inferred water-depth reconstruction. *Palaeogeography, Palaeoclimatology, Palaeoecology* 199: 31-49
3. Anyah, R. O., F. H. M. Semazzi and L. Xie, 2006: Simulated Physical Mechanisms Associated with Climate Variability over Lake Victoria Basin in East Africa. *Monthly Weather Review*, 134: 3588–3609
4. Anyamba, A., C.J. Tucker and R. Mahoney, 2002: From El Niño to La Niña: Vegetation Response Patterns over East and Southern Africa during the 1997–2000 Period. *Journal of Climate*, 15: 3,096-3,103
5. Asbjornsen, H., G. R. Goldsmith, *et al.*, 2011: Ecohydrological advances and applications in plant–water relations research: a review. *Journal of Plant Ecology*, 4: 3-22
6. Avery, S., 2010: Hydrological impacts of Ethiopia's Omo basin on Kenya's Lake Turkana water levels & fisheries. Report. African Development Bank, Tunis.
7. Barbier, E. B., *et al.*, 2008: Coastal ecosystem-based management with nonlinear ecological functions and values. *Science*, 319:321–323.
8. Battisti, D.S. and R.L. Naylor R.L., 2009: Historical warnings of future food insecurity with unprecedented seasonal heat. *Science* 323:240–244
9. Beaumont, L. J., McAllan, I. A. W. and Hughes, L., 2006: A matter of timing: changes in the first date of arrival and last date of departure of Australian migratory birds. *Global Change Biology* 12: 1339–1354
10. Belfiore, N.M, (ed.), 2010: The Implications of Global Climate Change for Mountain Gorilla Conservation. African Wildlife Foundation, the International Gorilla Conservation Programme, and EcoAdapt.
11. Black, E., J. Slingo, J. and K.R. Sperber, 2003: An observational study of the relationship between excessively strong short rains in coastal East Africa and Indian Ocean SST. *Monthly Weather Review*, 131: 74–94
12. Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda, 2007: Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge UK, 433-467.
13. Bond, W.J., G.F. Midgley and F.I. Woodward, F.I., 2003: The importance of low atmospheric CO₂ and fire in promoting the spread of grasslands and savannas. *Global Change Biology*, 9: 973–982
14. Bonnefille, R. and F. Chalé, 2000: Pollen-inferred precipitation time-series from equatorial mountains, Africa, the last 40 kyr BP. *Journal of Climate*, 26, 25–50
15. Brown, K. A., Flynn, D., Abram, N., Ingram, J.C., Johnson, S.E., and Wright, P., 2011: Assessing Natural Resource Use by Forest-Reliant Communities in Madagascar Using Functional Diversity and Functional Redundancy Metrics. *PLoS One*, 6: e24107
16. Camberlin, P., 1997: Rainfall Anomalies in the Source Region of the Nile and Their Connection with the Indian Summer Monsoon. *Journal of Climate*, 10, 1380–1392.
17. Camberlin, P., Janicot, S., Pocard, I., 2001: Seasonality and atmospheric dynamics of the teleconnection between African rainfall and tropical sea-surface temperature: Atlantic vs. ENSO. *International Journal of Climatology*, 21: 973–1005
18. Camberlin, P., B. Fontaine, S. Louvet, P. Oettli, P. Valimba, 2010: Climate Adjustments over Africa Accompanying the Indian Monsoon Onset. *Journal of Climate*, 23, 2047–2064
19. Camberlin, P., N. Philippon, 2002: The East African March–May Rainy Season: Associated Atmospheric Dynamics and Predictability over the 1968–97 Period. *Journal of Climate*, 15, 1002–1019
20. Carey, M., 2007: The History of Ice: How Glaciers Became an Endangered Species. *Environmental History* 12: 497-527
21. Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
22. Christy, J.R., W. B. Norris, and R. T. McNider, 2009: Surface temperature variations in east Africa and possible causes. *Journal of Climate*, 22, 3342–3356

23. Cohen, A.S., Stone, J.R., Beuning, K.R.M., Park, L.E., Reinthal, P.N., Dettman, D., Scholz, C.A., Johnson, T.C., King, J.W., Talbot, M.R., Brown, E.T., Ivory, S.J., 2007. Ecological Consequences of Early Late Pleistocene Megadroughts in Tropical Africa. *Proceedings of the National Academy of Science USA*, 104, 16422–16427
24. Collins, J.M., 2011: Temperature Variability over Africa. *Journal of Climate*, **24**, 3649–3666
25. Colls, A., N. Ash, and N. Ikkala, 2009: Ecosystem-based Adaptation: a natural response to climate change. Gland, Switzerland: IUCN.
26. Conway, D., E. Allison, R. Felstead and M. Goulden, 2005: Rainfall variability in East Africa: implications for natural resources management and livelihoods. *Philosophical Transactions of the Royal Society A*, 363: 49–54
27. Corlett, R., 2011: Impacts of warming on tropical lowland rainforests. *Trends in Ecology and Evolution*, 26: 606–613
28. Cross, M. S., E. S. Zavaleta, D. Bachelet, M. L. Brooks, C. A. F. Enquist, E. Fleishman, L. Graumlich, C. R. Groves, L. Hannah, L. Hansen, G. Hayward, M. Koopman, J. J. Lawler, J. Malcolm, J. Nordgren, B. Petersen, D. Scott, S. L. Shafer, M. R. Shaw, and G. M. Tabor. , n.d.: Adaptation for Conservation Targets (ACT) Framework: A tool for incorporating climate change into natural resource conservation and management. In review.
29. Dawson T.P., Jackson S.T., House J.I., Prentice I.C., Mace G.M., 2011: Beyond predictions: biodiversity conservation in a changing climate. *Science*, 332: 53–58
30. deMenocal, P.B., Ortiz, J., Guilderson, T., Adkins, J.F., Sarnthein, M., Baker, L., Yarusinsky, M., 2000: Abrupt onset and termination of the African Humid Period: rapid climate responses to gradual insolation forcing. *Quaternary Science Reviews* 19: 347–361
31. de Wit, M., and J. Stankiewicz, 2006: Changes in surface water supply across Africa with predicted climate change. *Science*, 311: 1917–1921
32. Diaz, H., Hoerling, M.P. & Eischeid, J.K. (2001) ENSO variability, teleconnections and climate change. *Int. J. Climatol.* 21, 1845–1862.
33. Diaz, H.F., Eischeid, J.K., Duncan, C., Bradley, R.S., 2003: Variability of freezing levels, melting season indicators and snow cover for selected high elevation and continental regions in the last 50 years. *Climatic Change*, 59: 33–52
34. Doherty, R. M., Sitch, S., Smith, B., Lewis, S. L. and Thornton, P. K., 2010: Implications of future climate and atmospheric CO₂ content for regional biogeochemistry, biogeography and ecosystem services across East Africa. *Global Change Biology*, 16: 617–640
35. Elenga, H., Peyron, O., Bonnefille, R., Jolly, D., Cheddadi, R., Guiot, J., Andrieu, V., Bottema, S., Buchet, G., De Beaulieu, J.-L., Hamilton, A. C., Maley, J., Marchant, R., Perez-Obiol, R., Reille, M., Rioulet, G., Scott, L., Straka, H., Taylor, D., Van Campo, E., Vincens, A., Laarif, F. and Jonson, H., 2000: Pollen-based biome reconstruction for southern Europe and Africa 18,000 yr bp. *Journal of Biogeography*, 27: 621–634
36. Ehrhart C., Thow A., de Blois A. and Warhurst A., 2009: Humanitarian Implications of Climate Change: Mapping emerging trends and risk hotspots. CARE International and Maplecroft.
37. Foden, W. B., G. M. Mace, J.-C. Vie, A. Angulo, S. H. M. Butchart, L. DeVantier, H. T. Dublin, A. Gutsche, S. Stuart, and E. Turak., 2009: Species susceptibility to climate change impacts. Pp. 77–88 in *Wildlife in a changing world – an analysis of the 2008 IUCN Red List of threatened species*, edited by J.-C. Vie, C. Hilton-Taylor, and S. N. Stuart. Gland: International Union for Conservation of Nature and Natural Resources.
38. Funk C, Dettinger M D, Michaelsen J C, Verdin J P, Brown M E, Barlow M and Hoell A ,2008: Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. *Proceedings of the National Academy of Science USA*, **105**: 11081–6
39. Garcia, R. A., Burgess, N. D., Cabeza, M., Rahbek, C. and Araújo, M. B., 2011: Exploring consensus in 21st century projections of climatically suitable areas for African vertebrates. *Global Change Biology*, in press
40. Gasse, F., 2000: Hydrological changes in the African tropics since the Last Glacial Maximum. *Quaternary Science Reviews*, 19: 189–211.
41. Giannini, A., M. Biasutti, I. M. Held and A. H. Sobel, 2008: A global perspective on African climate. *Climatic Change*, 90: 359–383
42. Goddard, L. and N.E. Graham, 1999: Importance of the Indian Ocean for simulating rainfall anomalies over eastern and southern Africa. *Journal of Geophysical Research* 104: 19099–19116
43. Gray, E., 2011: Climate Change Impacts to Key Ecosystems and People's Livelihoods in the Gombe-Masito-Ugalla and the Greater Mahale Project Area. The Nature Conservation and the Jane Goodall Institute
44. Hansen, J., R. Ruedy, M. Sato, and K. Lo, 2010: Global surface temperature change. *Review of Geophysics*, 48: RG4004

45. Hansen, J.E., and Mki. Sato, in press: Paleoclimate implications for human-made climate change. In *Climate Change: Inferences from Paleoclimate and Regional Aspects*. A. Berger, F. Mesinger, and D. Šijački, Eds. Springer.
46. Herrmann, S. M. and K. I. Mohr, 2011: A Continental-Scale Classification of Rainfall Seasonality Regimes in Africa Based on Gridded Precipitation and Land Surface Temperature Products. *Journal of Applied Meteorology and Climatology*, 50: 2504–2513
47. Hession, S. L. and N. Moore, 2011: A spatial regression analysis of the influence of topography on monthly rainfall in East Africa. *International Journal of Climatology*, 31: 1440–1456
48. Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005: Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25: 1965–1978
49. Hole, D.G., Willis, S.G., Pain, D.J., Fishpool, L.D., Butchart, S.H.M., Collingham, Y.C., Rahbek, C. and Huntley, B., 2009: Projected impacts of climate change on a continent-wide protected area network. *Ecology Letters*, 12: 420–431
50. ICASA, 2007: The International Consortium for Agricultural Systems Applications website. <http://www.icasa.net/index>. Html
51. Indeje, M., F. H. M. Semazzi, and L. J. Ogallo, 2000: ENSO signals in East African rainfall seasons. *International Journal of Climatology*, 20: 19–46
52. IPCC, 2007a: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
53. IPCC, 2007b: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson, eds., Cambridge University Press: Cambridge, UK.
54. Ivory, S.J., A-M. Lézine, A. Vincens and A.S. Cohen, 2012: Effect of aridity and rainfall seasonality on vegetation in the southern tropics of East Africa during the Pleistocene/Holocene transition. *Quaternary Research*, 77: 77-86
55. Jackson RB, Randerson JT, Canadell JG, Anderson RG, Avissar R, Baldocchi DB, Bonan GB, Caldiera K, Diffenbaugh NS, Field CB et al., 2008: Protecting climate with forests. *Environmental Research Letters*, 3:044006
56. Jansen, E. J., et al. (2007), Palaeoclimate, in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. Avery, M. Tignor, and H. Miller, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
57. Jolly, D. and A. Haxeltine, 1997: Effect of low glacial atmospheric CO₂ on tropical African montane vegetation. *Science*, 276:786–787
58. Jones P. G. and Thornton P. K., 2009: Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. *Environmental Science Policy*, 12: 427–437
59. Joos, F. and R. Spahni, 2008: Rates of change in natural and anthropogenic radiative forcing over the past 20,000 years. *Proceedings of the National Academy of Science USA*, 105: 1425–1430
60. Kallqvist, T., L. Lien and D. Liti, 1988: Lake Turkana, Limnological Study 1985–1988. Oslo, Norwegian Institute for Water Research
61. Kaser, G. et al., 2004: Modern Glacier Retreat on Kilimanjaro as Evidence of Climate Change: Observations and Facts, *International Journal of Climatology* 24: 336
62. Kingsford, R.T. and J.E.M. Watson, 2011: Climate Change in Oceania: a synthesis of biodiversity impacts and adaptations. *Pacific Conservation Biology*, 17: 270-84
63. Kingsford, R. T. 2011: Conservation management of rivers and wetlands under climate change – a synthesis. *Marine and Freshwater Research* 62: 217-222
64. Kinuthia, J. H., and G. C. Asnani, 1982: A newly found jet in north Kenya (Turkana channel). *Monthly Weather Review*, 110: 1722–1728
65. Kjøl, M., A. Nielsen and N.C. Stenseth, 2011: Potential effects of climate change on crop pollination. Food and Agriculture Organization of the United Nations, Rome
66. Konecky, B., Russell, J. M., Johnson, T. C., Brown, E. T., Huang, Y., Cohen, A. S., Werne, J., Berke, M., 2011. Isotopic variations in precipitation in Southeast Africa during the past 150,000 years. *Earth and Planetary Science Letters*, in press.

67. Latif, M., D. Dommenges, M. Dima, and A. Grotzner, 1999: The role of Indian Ocean sea surface temperature in forcing East African rainfall anomalies during December – January 1997/98, *Journal of Climate*, 12: 3497 – 3504
68. Lyon, B. and A. G. Barnston, 2005: ENSO and the Spatial Extent of Interannual Precipitation Extremes in Tropical Land Areas. *Journal of Climate*, 18: 5095–5109
69. Lyon, B. and D. G. DeWitt, 2012: A recent and abrupt decline in the East African long rains, *Geophysical Research Letters*, 39: L02702
70. Mackey, B. G., Watson, J.E.M., Hope, G. and S. Gilmore, 2008: Climate change, biodiversity conservation, and the role of protected areas: An Australian perspective. *Biodiversity*, 9:11-18.
71. Malhi, Y., C. Doughty, et al. (2011). "The allocation of ecosystem net primary productivity in tropical forests." *Philosophical Transactions of the Royal Society B: Biological Sciences* **366**(1582): 3225-3245
72. Marchant R, Mumbi C, Behera S, Yamagata T, 2006: The Indian Ocean dipole — the unsung driver of climatic variability in East Asia. *African Journal of Ecology*, 45: 4–16
73. McClanahan, T.R., J. Cinner, T. Daw, N. Graham, J. Maina, S. Stead, A. Wamukota, K. Brown, V. Venus and N. Polunin, 2009: Identifying Reefs of Hope and Hopeful Actions : Contextualizing Environmental, Ecological, and Social Parameters to Respond Effectively to Climate Change. *Conservation Biology* 23: 662-671
74. McClean, C.J., Lovett, J.C., Küper, W., Hannah, L., Sommer, J.H., Barthlott, W., Termansen, M., Smith, G.F., Tokumine, S. & Taplin, J.R.D., 2005: African plant diversity and climate change. *Annals of the Missouri Botanical Garden*, **92**: 139–152
75. McSweeney, C., G. Lizcano, M. New, X. Lu, 2010: The UNDP Climate Change Country Profiles. *Bulletin of the American Meteorological Society*, 91: 157–166
76. Meehl, G. A., W. M. Washington, J. M. Arblaster, H. Teng, C. Tebaldi, W. G. Strand, and J. B. White, 2011: Climate system response to external forcings and climate change projections in CCSM4, *Journal of Climate*, in press.
77. Mölg, T., H. Rott, G. Kaser, A. Fischer, and N. J. Cullen, 2006: Comment on “Recent glacial recession in the Rwenzori Mountains of East Africa due to rising air temperature” by Richard G. Taylor, Lucinda Mileham, Callist Tindimugaya, Abushen Majugu, Andrew Muwanga, and Bob Nakileza, *Geophysical Research Letters*, 33, L20404
78. Munyuli, M.B.T. 2011: Pollinator biodiversity in Uganda and in Sub-Sahara Africa: Landscape and habitat management strategies for its conservation. *International Journal of Biodiversity and Conservation*, 3: 551-609
79. Nicholson, S.E., J. Y. Kim, and J. Hoopingarner, 1988: Atlas of African Rainfall and Its Interannual Variability. The Florida State University
80. Nicholson, S. E., 2000: The nature of rainfall variability over Africa on time scales of decades to millennia, *Global Planetary Change*, 26: 137– 158
81. Ogallo, L.J., 1989. Spatial and temporal patterns of east African seasonal rainfall derived from principal component analysis. *International Journal of Climatology*, 9: 145-167
82. J. A. Omumbo, B. Lyon, S. M. Waweru, S. J. Connor, and M. C. Thomson, 2011: Raised temperatures over the Kericho tea estates: revisiting the climate in the East African highlands malaria debate. *Malaria Journal*, 10, article 12
83. Paeth, H., K. Born, R. Girmes, R. Podzun, and D. Jacob, 2009: Regional Climate Change in Tropical and Northern Africa due to Greenhouse Forcing and Land Use Changes. *Journal of Climate*, **22**, 114–132
84. Parmesan C. and G. Yohe, 2003: A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 421: 37-42
85. Picton Phillipps, G. and A. Seimon, 2009: Potential Climate Change Impacts in Conservation Landscapes of the Albertine Rift, Wildlife Conservation Society whitepaper. Available at: <http://www.albertinerift.org/DesktopModules/Bring2mind/DMX/Download.aspx?EntryId=11661&PortalId=49&DownloadMethod=attachment>
86. Platts, P.J., Ahrends, A., Gereau, R.E., McClean, C.J., Lovett, J.C., Marshall, A.R., Pellikka, P.K.E., Mulligan, M., Fanning, E. & Marchant, R., 2010: Can distribution models help refine inventory-based estimates of conservation priority? A case study in the Eastern Arc forests of Tanzania and Kenya. *Diversity and Distributions*, 16: 628–642
87. Plumptre, A.J., B. Kirunda, H. Mugabe, J. Stabach, M. Driciru, G. Picton-Phillipps, S. Ayebare, G. Nangendo and N. Laporte. 2010: The Impact of Fire and Large Mammals on the Ecology of Queen Elizabeth National Park
88. Plumptre, A. J. (ed.), 2012: The Ecological Impact of Long-term Changes in Africa's Rift Valley. New York: Nova Science Publishers.
89. Plumptre, A. J., T. R. B. Davenport, M. Behangana, R. Kityo, G. Eilu, P. Ssegawa, C. Ewango, et al. 2007: The Biodiversity of the Albertine Rift. *Biological Conservation*, 134:178–94

90. Poiani, K.A., R.L. Goldman, J. Hobson, J.M. Hoekstra and K. Nelson, 2010: Redesigning biodiversity conservation projects for climate change: examples from the field, *Biodiversity and Conservation* 20: 185-201
91. Poeschl, A., J. C. McManis, J. P. Giesbrecht, S. C. Singarayer, J. S. Boyle
S., 2005: Large temperature variability in the southern African tropics since the Last Glacial Maximum. *Geophysical Research Letters*, 32.
92. Reid, H., M. Alam, R. Berger, T. Cannon, S. Huq, and A. Milligan, 2009: Community-based adaptation to climate change: an overview. *Participatory Learning and Action*, issue 60. 13.
93. Root T.L., Price J.T., Hall K.R., Schneider S.H., Rosenzweig C., et al., 2003: Fingerprints of global warming on wild animals and plants. *Nature*, 421: 57-60
94. Rowland, E.L., J.E. Davison and L.J. Graumlich, 2011: Approaches to Evaluating Climate Change Impacts on Species: A Guide to Initiating the Adaptation Planning Process. *Environmental Management*, 47: 322-337
95. Russell, J.M. and T.C. Johnson, 2005: A high-resolution geochemical record from Lake Edward, Uganda Congo and the timing and causes of tropical African drought during the Late Holocene. *Quaternary Science Reviews*, 24: 1375-1389
96. Russell, J., H. Eggermont, R. Taylor and D. Verschuren, 2009: Paleolimnological records of recent glacier recession in the Rwenzori Mts, Uganda–D. R. Congo. *Journal of Paleolimnology*, 41: 253–271
97. Saji, N.H, B. N. Goswami, P. N. Vinayachandran and T. Yamagata 1999: A dipole mode in the tropical Indian Ocean, *Nature*, 401, 360-363
98. Salzmann, U., A.M Haywood and D.J Lunt, 2009: The past is a guide to the future? Comparing Middle Pliocene vegetation with predicted biome distributions for the twenty-first century. *Philosophical Transactions of the Royal Society A*, 367: 189-204
99. Scholz, C.A., King, J.W., Ellis, G.S., Swart, P.K., Stager, J.C., Colman, S.M., 2003: Paleolimnology of Lake Tanganyika, East Africa, over the past 100 kyr. *Journal of Paleolimnology*, 30: 139–150
100. Scholz, C.A., Johnson, T.C., Cohen, A.S., King, J.W., Peck, J., Overpeck, J.T., Talbot, M.R., Brown, E.T., Kalindekaffe, L., Amoako, P.Y.O., Lyons, R.P., Shanahan, T.M., Castaneda, I.S., Heil, C.W., Forman, S.L., McHargue, L.R., Beuning, K.R., Gomez, J., Pierson, J., 2007: East African megadroughts between 135–75 kyr ago and bearing on early-modern human origins. *Proceedings of the National Academy of Science USA*, 104: 16416–16421
101. Scholz, C.A., A. S. Cohen, T. C. Johnson, and J. W. King, 2011: Scientific Drilling in the Great Rift Valley: The 2005 Lake Malawi Scientific Drilling Project—An overview of the past 145,000 years of climate variability in Southern Hemisphere East Africa. *Palaeogeography. Palaeoclimatology. Palaeoecology*, 303: pp. 3–19
102. Schreck, C. J. and Semazzi, F. H. M., 2004: Variability of the recent climate of eastern Africa. *International Journal of Climatology*, 24: 681–701
103. Secretariat of the Convention on Biological Diversity, 2009: Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. Montreal, Technical Series No. 41.
104. Seimon, A., J. Watson, R. Dave and J. Oglethorpe et al., 2011: A Review of Climate Change Adaptation Initiatives within the Africa Biodiversity Collaborative Group NGO Consortium, Wildlife Conservation Society, New York, and Africa Biodiversity Collaborative Group, Washington DC
105. Seimon, A. and G. Picton Phillipps (2012): Regional Climatology of the Albertine Rift. In, A. Plumtre (Ed.), Long-term changes in Africa's Rift Valley, New York: Nova Science Publishers.
106. Shongwe, Mxolisi E., Geert Jan van Oldenborgh, Bart van den Hurk, Maarten van Aalst, 2011: Projected Changes in Mean and Extreme Precipitation in Africa under Global Warming. Part II: East Africa. *Journal of Climate*, 24: 3718–3733.
107. Siegenthaler U, Stocker TF, Monnin E, Luthi D, Schwander J, Stauffer B, Raynaud D, Barnola JM, Fischer H, Masson-Delmotte V, Jouzel J., 2005: Stable carbon cycle–climate relationship during the Late Pleistocene. *Science* 310: 1313–1317
108. Sitch, S., Smith, B., Prentice, I. C., Arneth, A., Bondeau, A., Cramer, W., Kaplan, J., Levis, S. Lucht, W., Sykes, M., Thonicke, K. and Venevsky, S., 2003: Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ Dynamic Vegetation Model. *Global Change Biology*, 9: 161 -185
109. Simmons, R., Barnard, P., Dean, W.R.J., Midgley, G.F., Thuiller, W. and Hughes, G., 2005: Climate change and birds: perspectives and prospects from southern Africa. *Ostrich*, 75: 295–308
110. Solomon, S., G.-K. Platter, R. Knutti, and P. Friedlingstein, 2009: Irreversible climate change due to carbon dioxide emissions, *Proceedings of the National Academy of Science USA*, 106: 1704-1709
111. Spahni, R. et al., 2005: Atmospheric methane and nitrous oxide of the Late Pleistocene from Antarctic ice cores. *Science* 310: 1317–1321
112. Stager, J. C., P. A. Mayewski, and L. D. Meeker, 2002: Cooling cycles, Heinrich Event 1, and the desiccation of Lake Victoria, *Palaeogeography. Palaeoclimatology. Palaeoecology*, 183: 169–178

113. Stampone, M.D., J. Hartter, C.A. Chapman and S.J. Ryan, 2011: Trends and Variability in Localized Precipitation Around Kibale National Park, Uganda, Africa. *Research Journal of Environmental and Earth Sciences* 3: 14-23
114. Hartter J, Stampone MD, Ryan SJ, Kirner K, Chapman CA, et al., 2012: Patterns and Perceptions of Climate Change in a Biodiversity Conservation Hotspot. *PLoS ONE*, 7: e32408
115. Taylor, R.G., L. Mileham, C. Tindimugaya, A. Majugu, A. Muwanga, and B. Nakizela, 2006: Recent glacial recession in the Rwenzori Mountains of East Africa due to rising air temperature. *Geophysical Research Letters*, 33: L10402
116. Thornton, P.K., P.G. Jones, G. Alagarswamy and J. Anresen, 2009: Spatial variation of crop yield response to climate change in East Africa. *Global Environmental Change*, 19: 54-65
117. Thornton P. K., Jones P. G., Ericksen P. J., Challinor A. J. 2011: Agriculture and food systems in sub-Saharan Africa in a 4°C+ world. *Philosophical Transactions of the Royal Society A*, 369: 117–136
118. Tierney, J.E., J.M. Russell, Y. Huang, J.S. Sinninghe Damste, E.C. Hopmans, and A.S. Cohen, 2008: Northern Hemisphere controls on tropical Southeast African climate during the past 60,000 years. *Science* 322, 252–255
119. Tierney, J.E., M.T. Mayes, N. Meyer, C. Johnson, P.W. Swarzenski, A.S. Cohen and J.M. Russell, 2010: The unprecedented warming of Lake Tanganyika. *Nature Geoscience*, 3: 422 – 425
120. Tierney, J.E., Russell, J.M., Sinninghe Damsté, J.S., Huang, Y., Verschuren, D., 2011: Late Quaternary behavior of the East African monsoon and the importance of the Congo Air Boundary. *Quaternary Science Reviews*, 30: 798–807
121. UNFCCC n.d.: United Nations Framework Convention on Climate Change. http://unfccc.int/essential_background/convention/background/items/2536.php Accessed on 15 Feb 2012
122. Ummenhofer, C.C., Gupta, A.S., England, M.H., Reason, C.J.C., 2009: Contributions of Indian Ocean sea surface temperatures to enhanced East African rainfall. *Journal of Climate*, 22: 993–1013
123. Van Vuuren, D.P., and co-authors, 2011: The representative concentration pathways: An overview. *Climatic Change*, in press.
124. Verburg, P., and R. E. Hecky, 2009: The physics of the warming of Lake Tanganyika by climate change, *Limnology and Oceanography*, 54: 2418–2430
125. Verburg, P., R. E. Hecky, and H. Kling, 2003: Ecological consequences of a century of warming in Lake Tanganyika, *Science*, 301: 505–507
126. Verschuren, D., Laird, K.R., Cumming, B.F., 2000: Rainfall and drought in equatorial East Africa during the past 1,100 years. *Nature* 403, 410–414
127. Verschuren, D., 2004: Decadal and century-scale climate variability in tropical Africa during the past 2000 years, In R. W. Battarbee et al. (eds) 2004. Past Climate Variability through Europe and Africa. Kluwer Academic Publishers, Dordrecht, The Netherlands.
128. Vincens, A., Chalé, F., Bonnefille, R., Guiot, J., Tiercelin, J.J., 1993: Pollen-derived rainfall and temperature estimates from Lake Tanganyika and their implication for Late Pleistocene water levels. *Quaternary Research*, 40, 343–350
129. Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Reidy Liermann, C. R. and Davies, P. M. 2010: Global threats to human water security and river biodiversity. *Nature*, 467: 555–561
130. Watson, J.E.M., Cross, M., Rowland, E., Joseph, L. N., Rao, M. and Seimon A. 2011: Planning for species conservation in a time of climate change. Climate Change Volume 3: Research and technology for climate change adaptation and mitigation. Pp 379-402. InTech Publishers.
131. Weber, S.L., 2009: The utility of earth-system models of inter- mediate complexity (EMICS). *WIREs Climate Change*, 1:243–252.
132. Whittaker R.J., Araújo M.B., Jepson P., Ladle R.J., Watson J.E.M., et al., 2005: Conservation Biogeography: assessment and prospect. *Diversity and Distributions*, 11: 3–23
133. Williams, J.W. and S.T. Jackson, 2007: Novel climates, no- analog communities, and ecological surprises. *Frontiers in Ecology and the Environment*, 5: 475–482
134. Williams, J.W., S.T. Jackson and J.E. Kutzbach, 2007: Projected distributions of novel and disappearing climates by 2100 AD. *Proceedings of the National Academy of Science USA*, 104: 5738–5742