



# Climate Change Impacts on East Africa

## A Review of the Scientific Literature

Africa contains about one-fifth of all known species of plants, mammals, and birds, as well as one-sixth of amphibians and reptiles. These species compose some of the world's most diverse and biologically important ecosystems such as savannahs, tropical forests, coral reef marine and freshwater habitats, wetlands and montane ecosystems. These globally important ecosystems provide the economic foundation that many Africa countries rely on by providing water, food, and shelter. However, because of climate change, these ecosystems and the livelihoods that depend on them are threatened. The aim of this report is to highlight some of the major impacts of climate change on conservation for East Africa countries including Kenya, Tanzania, Uganda and Rwanda.

As this paper illustrates, climate change in Africa is not only a conservation problem but is a socio-economic issue that must be dealt with at a global scale.

Climate change is real and happening now. The average global surface temperature has warmed 0.8°C in the past century and 0.6°C in the past three decades (Hansen *et al.*, 2006), in large part because of human activities (IPCC, 2001). A recent report produced by the U.S. National Academy of Sciences confirms that the last few decades of the 20th century were in fact the warmest in the past 400 years (National Research Council, 2006). The Intergovernmental Panel on Climate Change (IPCC) has projected that if greenhouse gas emissions, the leading cause of climate change, continue to rise, the mean global temperatures will increase 1.4 – 5.8°C by the end of the 21<sup>st</sup> century (IPCC, 2001).

The effects of climate change such as rising temperature and changes in precipitation are undeniably clear with impacts already affecting ecosystems, biodiversity and people. In both developed and developing countries, climate impacts are reverberating through the economy, from threatening water availability to sea-level rise and extreme weather impacts to coastal regions and tourism. In some countries, climate impacts affect the ecosystem services that communities are largely dependent upon, threatening development and economic stability. Future impacts are projected to worsen as the temperature continues to rise and as precipitation becomes more unpredictable.

One region of the world where the effects of climate change are being felt particularly hard is Africa. Because of the lack of economic, development, and institutional capacity, African countries are likely among the most vulnerable to the impacts of climate change (IPCC, 2001). Climate change impacts have the potential to undermine and even, undo progress made in improving the socio-economic well-being of East Africans. The negative impacts associated with climate change are also compounded by many factors, including widespread poverty, human diseases, and high population density, which is estimated to double the demand for food, water, and livestock forage within the next 30 years (Davidson *et al.*, 2003).

# Summary

## Observed Climatic Changes (Hulme et al., 2001; IPCC, 2001)

- Warming of 0.7°C over the 20th century for Africa
- 0.05°C warming per decade through the 20th century
- Increased precipitation for East Africa

## Projected Climate Change (Hulme et al., 2001; IPCC, 2001)

- Projected warming for Africa ranges from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario)
- 5-20% increase in precipitation from December-February (wet months)
- 5-10% decreased in precipitation from June-August (dry months)

## Climate Change Impacts:

### • **Water availability**

- Warm sea surface temperatures may lead to increased droughts in equatorial and subtropical Eastern Africa (Funk et al., 2005)
- Less precipitation during already dry months can lead to drought and increased desertification (IPCC, 2001)
- Annual flow reductions of 6-9% of in the River Pangani and 10% in the River Ruvu (Tanzania) (VPO-URT, 2003)
- Complete disappearance of Kilimanjaro's glaciers by 2015 - 2020 (Thompson et al. 2002)

### • **Food security**

- Decline in long-cycle crops and rainfall between March and May from 1996 to 2003 (Funk et al., 2005)
- El Niño events produce abnormally high amounts of precipitation in parts of equatorial East Africa and can result in flooding and decreased agricultural yields (IPCC, 2001)
- Warming temperatures may negatively affect some fisheries in the region (Roessig et al., 2004)
- Warm temperatures may also lead to faster depletion of the limited oxygen supply, negatively affecting fisheries, and limiting lake overturn (Fick et al., 2005)

### • **Human health**

- Climate change is expected to exacerbate the occurrence and intensity of future disease outbreaks and may increase the spread of diseases in some areas (IPCC, 2001)
- Rainfall and unusually high maximum temperatures are positively correlated with the number of malaria cases (Githeko and Ndegwa, 2001; Zhou et al., 2004)
- Climate change resulting in warm and rainy days can lead to incidences of malaria events (Craig et al., 2004)
- Temperature affects the development rates of vectors and parasites while rainfall affects the availability of mosquito breeding sites (Zhou et al., 2004; Craig et al., 2004)
- Rift Valley fever outbreaks are positively correlated with El Niño events (Patz et al., 2005).

### • **Extreme Weather Events**

- Warming temperatures are projected to cause more frequent and more intense extreme weather events, such as heavy rain storms, flooding, fires, hurricanes, tropical storms and El Niño events (IPCC, 2001)

- Lake levels in Lake Tumba in the Democratic Republic of Congo (Inogwabini et al., 2006) and Lake Victoria (Birkett et al., 1999; Latif et al., 1999) have been attributed to climate variations and may become more variable in the future
  - Climate change is projected to cause more frequent and intense ENSO events, leading to widespread drought in some areas and widespread flooding in others (Wara et al., 2005)
  - Warming temperatures are projected to cause more frequent and intense hurricanes and tropical storms that inundate coastal areas (IPCC, 2001)
- **Sea-Level Rise**
    - Warm sea surface temperatures, more extreme weather events, and sea-level rise will lead to the destruction of coral reefs, which are crucial for coastal protection (IPCC, 2001)
    - Mangroves are at threat from deforestation, coastal erosion and extreme weather and have been identified as one of the most vulnerable species to sea-level rise and inundation (IPCC, 2001)
    - A temperature increase of 1.2°C and the resulting changes in precipitation, soil moisture and water irrigation would cause large areas of land that now support tea cultivation in Kenya to be largely unusable (Simms, 2005)
- **Biodiversity**
    - Climate change is expected to significantly alter African biodiversity as species struggle to adapt to changing conditions (Lovett et al., 2005)
    - Biome sensitivity assessments in Africa show deciduous and semi-deciduous closed-canopy forests may be very sensitive to small decreases in precipitation during the growing season. This illustrates that deciduous forests may be more sensitive to reduced precipitation than grasslands or savannahs (Hily et al., 2006)
    - Invasive species and other species with high fertility and dispersal capabilities have been shown to be highly adaptive to variable climatic conditions (Malcolm et al., 2002)
    - Climate change has the potential to alter migratory routes (and timings) of species that use both seasonal wetlands (e.g., migratory birds) and track seasonal changes in vegetation (e.g., herbivores). This may for instance increase conflicts between people and large mammals such as elephants, particularly in areas where rainfall is low (Thirgood et al., 2004)
    - A change in the intensity or duration of the rainy versus dry seasons could change relative breeding rates and, hence, genetic structures in these populations (Poole, 1989; Rubenstein, 1992)
    - Large changes in ecosystem composition and function because of regional climate change would have cascading effects on species diversity (Sykes and Prentice, 1996; Solomon and Kirilenko, 1997; Kirilenko and Solomon, 1998)
    - In sub-Saharan Africa, which includes parts of East Africa, several ecosystems, particularly grass and shrub savannahs, are shown to be highly sensitive to short-term availability of water due to climate variability (Vanacker et al., 2005)
    - Climate projections suggest that during already dry months, less precipitation will occur, reducing the resilience of plants (Vanacker et al., 2005)  
Species ranges will probably not shift in cohesive and intact units and are likely to become more fragmented as they shift in response to changing climate (Channel and Lomolino, 2000).

# Observed and Projected Climate Change

Overall Africa has warmed 0.7°C over the 20<sup>th</sup> century and general circulation models project warming across Africa ranging from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario) (Hulme *et al.*, 2001; IPCC, 2001).

For comparison, warming through the 20<sup>th</sup> century was at the rate of about 0.05°C per decade. Precipitation patterns in East Africa are more variable; however, historical records indicate that there has been an increase in rainfall over the last century (Hulme *et al.*, 2001; IPCC, 2001). Hulme *et al.*, (2001), suggest that under intermediate warming scenarios, parts of equatorial East Africa will likely experience 5-20% increased rainfall from December-February and 5-10% decreased rainfall from June-August by 2050. Climatic changes of this magnitude will have far-reaching, negative impacts on the availability of water resources, food and agricultural security, human health, tourism, coastal development and biodiversity and are highlighted below.

## I. Water Availability

Arguably one of the most widespread and potentially devastating impacts of climate change in East Africa will be changes in the frequency, intensity, and predictability of precipitation. Changes in regional precipitation will ultimately affect water availability and may lead to decreased agricultural production and potentially widespread food shortages.

Projections of climate change suggest that East Africa will experience warmer temperatures and a 5-20% increased rainfall from December-February and 5-10% decreased rainfall from June-August by 2050 (Hulme *et al.*, 2001; IPCC, 2001). Not only are these changes not uniform throughout the year, they will likely occur in sporadic and unpredictable events. It may also be likely that the increased precipitation will come in a few very large rainstorms mostly during the already wet season thereby adding to erosion and water management issues and complicating water management. It is also expected that there will be less precipitation in East Africa during the already dry

season, which may cause more frequent and severe droughts and increased desertification in the region.

Recent research also suggests that warming sea surface temperatures, especially in the southwest Indian Ocean, in addition to inter-annual climate variability (i.e., El Niño/Southern Oscillation (ENSO)) may play a key role in East African rainfall and may be linked to the change in rainfall across some parts of equatorial-subtropical East Africa (Cane *et al.*, 1986; Plisnier *et al.*, 2000; Rowe, 2001). Warm sea surface temperatures are thought to be responsible for the recent droughts of in equatorial and subtropical Eastern Africa during the 1980s to the 2000s (Funk *et al.*, 2005). According to the U.N. Food and Agriculture Organization (FAO, 2004), the number of African food crises per year has tripled from the 1980s to 2000s. Drought diminished water supplies reduce crop productivity and have resulted in widespread famine in East Africa.

In addition to declining moisture needed for pastoral and agricultural activities, the availability of water for human consumption is of paramount concern. Currently, two-thirds of rural Africans and a quarter of urban dwellers in Africa lack access to clean, safe drinking water (Simms, 2005). In Tanzania, for example, two of three rivers have reduced flow due to declining regional rainfall, which has had ecological and economic impacts such as water shortages, lowered agricultural production, increased fungal and insect infestations, decreased biodiversity and variable hydropower production (Orindi and Murray, 2005). High temperatures and less rainfall during already dry months in the Tanzanian river catchments could affect the annual flow to the River Pangani by reductions of 6-9% and to the River Ruvu by 10% (VPO-URT, 2003). The Pangani Basin is also fed by the glaciers of Kilimanjaro, which have been melting alarmingly fast and are estimated to disappear completely by 2015 - 2020 (Thompson *et al.* 2002). The population living around the base of Kilimanjaro uses this meltwater and the fog water from the rainforests that cover the mountain's flanks for drinking, irrigation, and hydropower. The Pangani Basin is one of Tanzania's most agriculturally productive areas and is an

important hydropower production region. Because of this, climate change threatens the productivity and sustainability of this region's resources, which hosts an estimated 3.7 million people.

## II. Food Security

There is a strong link between climate and East African livelihoods. East Africa depends heavily on rain-fed agriculture making rural livelihoods and food security highly vulnerable to climate variability such as shifts in growing season conditions (IPCC, 2001). Further, agriculture contributes 40% of the region's gross domestic product (GDP) and provides a living for 80% East Africans (IFPRI, 2004). However because temperature has increased and precipitation in the region has decreased in some areas, many are already being affected. For example, from 1996 to 2003, there has been a decline in rainfall of 50-150 mm per season (March to May) and corresponding decline in long-cycle crops (e.g., slowly maturing varieties of sorghum and maize) across most of eastern Africa (Funk *et al.*, 2005). Long-cycle crops depend upon rain during this typically wet season and progressive moisture deficit results in low crop yields in the fall, thereby impacting the available food supply.

Increased variability (i.e., deviation from the mean) of crop production is also a major concern of farmers in eastern Africa. Inter-annual climate variability (e.g., ENSO) has huge impacts on the region's climate. Warm ENSO events also referred to as El Niño events produce abnormally high amounts of precipitation in parts of equatorial East Africa and can result in flooding and decreased agricultural yields. Further south, in Zimbabwe, researchers correlated past El Niño events and warm sea surface temperatures in the eastern equatorial Pacific with more than 60% of the change between above and below average agricultural production of maize (Patt *et al.*, 2005).

Climate change may also impact the region's fisheries. While many tropical fishes have evolved to survive in very warm water, many have a critical thermal maxima and can not survive temperatures that exceed this threshold. For example, spotted

tilapia, (*Tilapia mariae*), native to parts of Africa, prefer temperatures between 25 and 33°C, depending upon acclimation temperature, and have a critical thermal maxima of 37°C (Siemien and Stauffer 1989). Though tropical fishes can endure temperatures very near their temperature threshold, a slight (1 – 2°C) increase in regional temperatures may cause the daily temperature maxima to exceed these limits, particularly for populations that currently exist in thermally marginal habitats (Roessig *et al.*, 2004). However, because there is little data on the ability of this species to adjust their tolerance to water temperature their response to climate change is largely unknown.

An increase in mean temperature may also affect the dissolved oxygen concentrations in the layer of water below the thermocline (hypolimnion) in two ways: increased metabolism of fish and other organisms in a slightly warmer hypolimnion will lead to the faster depletion of the limited oxygen supply, and lake overturn, the primary means of replenishing hypolimnetic dissolved oxygen, will occur less frequently (Fick *et al.*, 2005). The African Great Lakes contain deep anoxic hypolimnia that serve as nutrient stores. The anoxic hypolimnia of tropical lakes also contain high concentrations of hydrogen sulfide. This chemical compound is a byproduct of anaerobic decomposition of organic matter and is highly toxic to fish. Moderate amounts of mixing allow nutrient influx into the layer of water above the thermocline and benefit fisheries productivity without introducing high concentrations of toxic hydrogen sulfide (Fick *et al.*, 2005). This is demonstrated at the stratified northern end of Lake Tanganyika, Africa, which supports a less productive fishery than the well-mixed southern arm and the main basins (Vuorinen *et al.*, 1999). A comparative study of historical and current levels of primary production in the north end of Lake Tanganyika indicated that current levels are much lower as a result of strengthened stratification (Verburg *et al.*, 2003). Recent changes in the limnology of Lake Victoria have also negatively affected its fishery. In the 1980's decreased turnover in the lake led to low levels and dissolved oxygen and, consequently, fish kills. Stratification in this lake now appears to be permanent (Kaufman *et al.*, 1996).

### III. Human Health

Climate variability has had far-reaching effects to human health, and includes, but is not limited to, the following: heat stress, air pollution, asthma, vector-borne diseases (such as malaria, dengue, schistosomiasis (also referred to as swimmer's itch or snail fever) and tick-borne diseases), water-borne and food-borne diseases (such as diarrhoeal diseases). For this report, we concentrate on just two of these effects, malaria and Rift Valley fever; however, other health issues are likely to be affected by climate change.

Climate change is expected to exacerbate the occurrence and intensity of future disease outbreaks and perhaps increase the spread of diseases in some areas. It is known that climate variability and extreme weather events, such as high temperatures and intense rainfall events, are critical factors in initiating malaria epidemics especially in the highlands of western Kenya, Uganda, Ethiopia, Tanzania, Rwanda and Madagascar (Zhou *et al.*, 2004). While other factors, such as topography and health preparedness can influence the spread of malaria, scientists have found a correlation between rainfall and unusually high maximum temperatures and the number of malaria cases (Githeko and Ndegwa, 2001; Zhou *et al.*, 2004). From 1920 to 1950, the highlands of eastern Africa experienced infrequent malaria outbreaks; however, since then, the current pattern is characterized by increased outbreak frequencies, expanded geographic range, and increased case-fatality rates (Zhou *et al.*, 2004). The survival of mosquito vectors (*Anopheles spp.*) and the mosquito parasite that causes malaria (*Plasmodium falciparum*) are also affected by climate. Temperature affects the development rates of vectors and parasites while rainfall affects the availability of mosquito breeding sites (Zhou *et al.*, 2004; Craig *et al.*, 2004). The spread of malaria is seasonal and limited to the warm and rainy months; however, changing climate conditions, such as the persistence of warm and rainy days for more of the year can increase the incidence of malaria events (Craig *et al.*, 2004). In addition to longer seasons that are suitable for malaria spread, temperatures have also been warming in formerly cooler, higher-elevation East African highlands. Subsequently, these areas are experiencing a spread of malaria in populations that had not previously been

frequently exposed to the disease (Patz *et al.*, 2005; Zhou *et al.*, 2004).

Rift Valley Fever epidemics are also correlated to climate variability. Between 1950 and 1998 three quarters of the Rift Valley Fever outbreaks occurred during warm ENSO event periods (i.e., El Niño events). During El Niño, the East African highlands typically receive unusually high rainfall which is correlated with Rift Valley Fever outbreaks (Patz *et al.*, 2005).

### IV. Extreme Weather Events

Warming temperatures are projected to cause more frequent and more intense extreme weather events, such as heavy rain storms, flooding, fires, hurricanes, tropical storms and El Niño events (IPCC, 2001). Tropical storms can ravage coastal areas and intensify the impacts of sea-level rise by accelerating erosion in coastal areas and by removing protective natural buffer areas that absorb storm energy, such as wetlands and mangroves (Magadza, 2000). Extreme rainfall and subsequent heavy flooding damage will also have serious effects on agriculture including the erosion of topsoil, inundation of previously arid soils, and leaching nutrients from the soil. Regional fluctuations in lake levels are another impact of regional climate variations and are expected to worsen with projected climate change. While land use change can have a dramatic effect on lake levels, climate variability is more unpredictable and difficult to manage for. For example, lake levels in Lake Tumba in the Democratic Republic of Congo (Inogwabini *et al.*, 2006) and Lake Victoria in Kenya (Birkett *et al.*, 1999; Latif *et al.*, 1999) have been attributed to climate variations and may become more variable in the future. In 1997, floods and high rainfall, triggered by an El Niño event in eastern Africa, resulted in a surface rise of 1.7 meters in Lake Victoria and disrupted agricultural production and pastoral systems (Lovett *et al.*, 2005). While climate change is projected to cause more frequent and intense ENSO events (Wara *et al.*, 2005), impacts are not uniform across East Africa. In fact, the same year that the waters were rising in Lake Victoria, El Niño triggered a severe drought in another location in Kenya, significantly decreasing hydro-electric power output, limiting the availability of electricity to East Africans (Lovett *et al.*, 2005). Further, a projected

increase in precipitation may also have an effect on hurricanes and storms in the Atlantic. Landsea and Gray (1992) have found that rainfall in the Sahel is positively correlated with the intensity of hurricanes in the Atlantic Ocean.

Climate change-induced, warming land and sea surface temperatures are projected to cause more frequent and intense hurricanes and tropical storms that inundate coastal areas (IPCC, 2001). These same extreme weather events can lead to decreased precipitation in interior regions, causing increased drought and desertification, subsequently threatening food security. Threats to food security can then lead to widespread migration of human settlements in order to seek better agricultural land, more available water resources, and escape increased exposure to malaria and other diseases. The impacts of climate change also have the potential to disrupt and potentially reverse progress made in improving the socio-economic well-being of East Africans such as infrastructure development, sustainable agriculture, and tourism.

## V. Sea-Level Rise

Sea-level rise along coastal areas where high human populations occur is likely to disrupt economic activities there, such as tourism, mining and fisheries. Sea-level rise and resulting coastal erosion is of particular concern coastal Kenya and Tanzania. Warm sea surface temperatures, extreme weather events, and sea-level rise can lead to the destruction of coral reefs, which absorb the energy of ocean swells (IPCC, 2001). Coral reef loss is a significant cause of coastal erosion and a major coastal management issue in both Kenya and Tanzania (Magadza, 2000).

Productive mangrove ecosystems along coastal areas serve as a buffer against storm surges by providing protection from erosion and rising tides associated with sea-level rise. However, mangroves are at threat from deforestation, coastal erosion and extreme weather and have been identified as the most vulnerable species to sea-level rise and inundation (IPCC, 2001). Sea-level rise is also threatening the availability of freshwater by causing salt water intrusion into Tanzania's aquifers and deltas.

In the tea-producing regions of Kenya, the world's second largest exporter of tea, a small temperature increase (1.2 °C from now) and the resulting changes in precipitation, soil moisture and water irrigation would cause large areas of land that now support tea cultivation to be largely unusable. Economically, this would have far-reaching impacts because tea exports account for roughly 25% of Kenya's export earnings and employs about three million Kenyans (10% of its population) (Simms, 2005).

## VI. Biodiversity

Despite Africa's fast-growing human population and the associated impacts on natural resources, it is one of the least studied continents in terms of ecosystem dynamics and climate variability (Hély *et al.*, 2006). However, climate change is already having an impact on the dynamics of African biomes and its rich biodiversity, although species composition and diversity is expected to change due to individual species response to climate change conditions (Erasmus *et al.*, 2002). The projected rapid rise in temperature combined with other stresses, such as the destruction of habitats from land use change, could easily disrupt the connectedness among species, transforming existing communities, and showing variable movements of species through ecosystems, which could lead to numerous localized extinctions. If some plant species are not able to respond to climate change, the result could be increased vulnerability of ecosystems to natural and anthropogenic disturbance, resulting in species diversity reductions (Malcolm *et al.*, 2002).

Climate change is expected to significantly alter African biodiversity as species struggle to adapt to changing conditions (Lovett *et al.*, 2005). Historically, climate change has resulted in dramatic shifts in the geographical distributions of species and ecosystems and current rates of migration of species will have to be much higher than rates during post-glacial periods in order for species to adapt (Malcolm *et al.*, 2002). Species that have the capability to keep up with climate shifts may survive; others that cannot respond will likely suffer. For example, biome sensitivity assessments in Africa show that deciduous and semi-deciduous closed canopy forests may be

very sensitive to small decreases in the amount of precipitation that plants receive during the growing season, illustrating that deciduous forests may be more sensitive than grasslands or savannahs to reduced precipitation (Hély *et al.*, 2006). Invasive species and other species with high fertility and dispersal capabilities have been shown to be highly adaptive to variable climatic conditions (Malcolm *et al.*, 2002). Due to its climate sensitive native fauna, East Africa may be particularly vulnerable to exotic and invasive species colonization.

Migratory species that use Africa may also be vulnerable to changes in climate. In fact, climate change has the potential to alter migratory routes (and timings) of species that use both seasonal wetlands (e.g., migratory birds) and track seasonal changes in vegetation (e.g., herbivores), which may also increase conflicts with humans, particularly in areas where rainfall is low (Thirgood *et al.*, 2004). Land-use patterns in Africa can also prevent animals from changing their migratory routes, for example, park boundary fences have been demonstrated to disrupt migratory journeys, leading to a population decline in wildebeest (Whyte and Joubert 1988).

Climate change also threatens some of the large protected areas (including ones that protect migratory species) that have been designated to conserve much of Africa's magnificent biodiversity. It is expected that vegetation will migrate or move in order to utilize suitable habitats requirements (i.e., water and nutrient availability); however, this may mean that in some locations the geographical range of suitable habitats will shift outside the protected area boundaries. In addition, weather extremes can also affect biodiversity in more complex ways. For example, in African elephants (*Loxodonta africana*), breeding is year-round, but dominant males mate in the wet season and subordinate males breed in the dry season. Subsequently, a change in the intensity or duration of the rainy versus drought seasons could change relative breeding rates and, hence, genetic structures in these populations (Poole, 1989; Rubenstein, 1992). Strategies for future designations of protected areas in East Africa need to be developed that include projections of future climate change and corresponding changes in the geographic range of plant and animal species to ensure adequate protection.

Large changes in ecosystem composition and function because of regional climate change would

have cascading effects on species diversity (Sykes and Prentice, 1996; Solomon and Kirilenko, 1997; Kirilenko and Solomon, 1998). Vast forest disappearance due to climate change-induced die-back and land use change would substantially affect species composition and global geochemical cycling, particularly the carbon cycle (Malcolm *et al.*, 2002). In the savannahs of Zambia, research shows that climate change substantially affects growth in certain tree species. Chidumayo (2005) showed that dry tropical trees suffer severe water stress at the beginning of the growing season and that a warmer climate may accelerate the depletion of deep-soil water that tree species depend on for survival. In sub-Saharan Africa, which includes parts of East Africa, several ecosystems, particularly grass and shrub savannahs, are shown to be highly sensitive to short-term availability of water due to climate variability (Vanacker *et al.*, 2005). Shrub and grassland vegetation types generally have root systems that are shallow and dense; these plants draw their moisture from water that is available in upper soil layers and growth in these species depends highly upon the timing, intensity and duration of rainfall. Climate projections suggest that during already dry months, less precipitation will occur likely reducing the resilience of these plants (Vanacker *et al.*, 2005). Changes in plant composition will also have an impact on ecosystem resilience; less diverse systems can be more sensitive to precipitation fluctuations. For example, ecosystems that are comprised of uniform herbaceous cover, such as in savannah plant communities, show the highest sensitivity to precipitation fluctuations when compared with plant communities of a mix of herbaceous, shrub and tree species that support a higher diversity of species (Vanacker *et al.*, 2005).

Climate change may also affect species range, which could have profound impacts on species population size. For example, in South Africa a modeling study found that a reduction in the range of a species is likely to have an increased risk in local extinction climate change (Erasmus *et al.*, 2002). The authors suggest that this may be due to the positive inter-specific relationship between population size and range size; if range size decreases, there is likelihood that there will be a rapid decline in population size. Additionally, this relationship could be exacerbated if climate change restricts the range of a species to just a few key sites and an extreme weather event occurs, thus driving up extinction rates even further (Erasmus



*et al.*, 2002). Species ranges will probably not shift in cohesive and intact units and are likely to become more fragmented as they shift in response to changing climate (Channel and Lomolino, 2000). In fact, up to 66% of species may be lost due to predicted range shifts caused by climate change in

South Africa's Krueger National Park (Erasmus *et al.*, 2002). To be able to better conserve biodiversity in the future, it is imperative to understand how species and ecosystems are likely to change under varying climate change scenarios (Erasmus *et al.*, 2002).

## Building Resilience & Resistance to Climate Change

Both short and long-term adaptation strategies in response to regional climate change are beginning to emerge in a region that is rife with challenges. For every USD\$1 spent preparing for disaster, USD\$7 is spent recovering from disaster (Simms, 2005). As organizations test and develop new conservation concepts, it is clear that poverty alleviation must be considered with the conservation of nature and biodiversity. As some resources become scarce, conflicts between conservation and other land uses are likely to increase under climate change scenarios. However, human communities across Africa are banding together cooperatively to conserve resources and protect their livelihoods.

Along the Tanzanian coast, leading conservation groups are working with natural resource managers and other stakeholders to integrate climate change adaptation strategies into their management philosophies and plans (Hansen *et al.*, 2003). Initial vulnerability assessments and adaptation planning from Tanzania point to the need for mangrove protection, reforestation with "climate-smart species", integrated land-use and marine planning, as well as activities to improve resource use technology. Coordinating the testing of adaptation methods in geographically diverse locations within a common habitat type aims to increase the replicability so that the project results can be transferred to other conservation efforts around the globe (Hansen *et al.*, 2003).

Conservation of ecosystems and natural resources requires that adaptive management strategies are developed or that we accept that many natural systems will be lost to climate change.

Projects should aim to build the capacity of natural resource managers to assess vulnerability and to adapt management strategies to respond to expected climate change impacts (Hansen *et al.*, 2003).

Climate change impacts to rural farming communities can be reduced by distributing climate data regarding seasonal climate forecasts (based on short-term and long-term forecasts) to small farmers so that they can make more informed farming decision and adapt to the changing climate conditions. Some farmers have already started to use this information and are preparing themselves for dry conditions by planting drought-tolerant crops (Patt *et al.*, 2005). Food production can be improved dramatically in dry areas when governments and/or organizations use climate forecasts and prepare accordingly by potentially distributing drought-tolerant seeds (Patt *et al.*, 2005). Farmers can also take advantage of climate forecasts by planting less drought-tolerant and higher-yield, long season maize when wetter than usual growing seasons are forecast (Patt *et al.*, 2005). While seasonal forecasts can be useful in some situations, it should be noted that they can not be applied everywhere and that many times they do not consider multiple climate extremes, for example, they may forecast drought but not extreme rainfall. The aforementioned approaches are just a few of the many examples that governments, organizations, and communities need to consider in order to adapt to the challenges of subsistence food production and assure future food security (Patt *et al.*, 2005; Ziervogel, 2004).

Author and contact: Michael Case, WWF Climate Change Scientist, [michael.case@wwfus.org](mailto:michael.case@wwfus.org)

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