Climate vulnerability of biophysical systems in different forest types and coastal wetlands in Africa: a synthesis

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SUMMARY

This article synthesizes information on climate vulnerability of biophysical systems in forests, woodlands and coastal wetlands of Africa. Current knowledge indicates that forests and woodlands are sensitive to changes in precipitation, temperature and droughts and are already experiencing dramatic shift in species distribution. They are also undergoing changes in composition, structure and recovery potential due to increased anthropogenic activities exacerbated by climate change. Sea level rise is the greatest climate change challenge that coastal wetlands will face. It can affect coastal wetlands through alteration of inundation period, erosion and salt water intrusion. However, outcomes of interacting factors like temperature increase, variability in precipitation, extreme weather events and carbon dioxide concentration in forests and woodlands are uncertain. Research and models on climate vulnerability in different forest types should be done to improve understanding of climate vulnerability of biophysical systems, adaptation and mitigation potentials thereby guaranteeing achievements of Millennium Development Goals.

Keywords: Africa, forest ecosystems, climate change, climate vulnerability, biophysical systems

Vulnérabilité climatique des systèmes biophysiques dans différents types de forêts et dans les terres humides côtières en Afrique : une synthèse

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Cet article offre une synthèse sur la vulnérabilité climatique des systèmes biophysiques dans les forêts, les terres boisées et les terres côtières humides d'Afrique. La connaissance actuelle indique que les forêts et les terres boisées sont sensibles aux changements de précipitations, de température et à la sècheresse, et sont déjà témoins de changements dramatiques dans la distribution des espèces. Elles subissent également des changements dans leur composition, leur structure et leur potentiel de rétablissement, dus aux activités anthropogéniques accrues, exacerbés par le changement climatique. L'élévation du niveau des mers est le changement climatique le plus important auquel les terres côtières humides vont devoir faire face. Elle peut affecter ces dernières à travers des périodes d'altération et d'inondation, l'érosion et l'intrusion d'eau salée. Cependant, les résultats ultimes des facteurs en interaction comme l'augmentation de la température, la variabilité des précipitations, les épisodes météorologiques extrêmes et la concentration de gaz carbonique dans les forêts et les terres boisées demeurent incertains. Une recherche devrait être entreprise et des modèles de vulnérabilité climatique dressés pour différents types de forêts, en vue d'améliorer la compréhension de la vulnérabilité climatique des systèmes biophysiques, et de leurs potentiels d'adaptation et d'atténuation, afin de garantir la réussite des Objectifs du millenaire pour le developpement.

La vulnerabilidad climática de los sistemas biofísicos en diferentes tipos de bosques y humedales costeros de África: una síntesis

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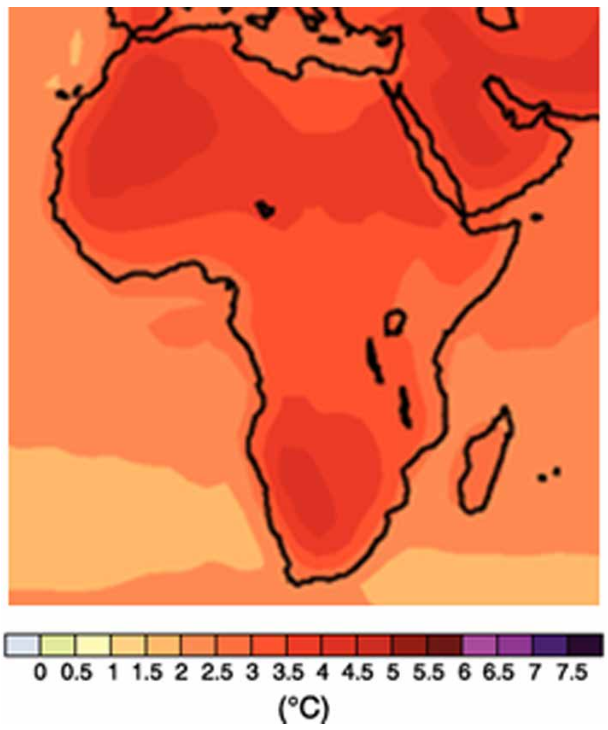
Este artículo sintetiza información sobre la vulnerabilidad climática de los sistemas biofísicos en los bosques, terrenos forestales y humedales costeros de África. El conocimiento actual indica que los bosques y los terrenos forestales son sensibles a los cambios en la precipitación, la temperatura y los períodos de sequía y que ya están experimentando cambios dramáticos en la distribución de las especies. También están experimentando cambios en la composición, la estructura y el potencial de recuperación debido a un aumento en las actividades antropogénicas exacerbado por el cambio climático. El aumento del nivel del mar es el mayor desafío del cambio climático al que se enfrentarán los humedales costeros. Estos se pueden ver afectados debido a la alteración del período de inundación, la erosión y la intrusión de agua salada. Sin embargo, los efectos de la interacción de factores tales como el aumento de la temperatura, la variabilidad de las precipitaciones, los fenómenos meteorológicos extremos y la concentración de dióxido de carbono en los bosques y terrenos forestales son inciertos. Se debería hacer investigación y desarrollar modelos sobre la vulnerabilidad climática en diferentes tipos de bosque para mejorar la comprensión de la vulnerabilidad climática de los sistemas biofísicos, y los potenciales de adaptación y de mitigación, para garantizar con ello el logro de los Objetivos de Desarrollo del Milenio.

INTRODUCTION

There is compelling evidence that in Africa climate has changed considerably over the past two centuries and this is demonstrated by the increasing mean temperature observed over time (IPCC 2007). Climate change models show that during the 20th century the African continent was warmer than it was 100 years ago with warming of about 0.7ºC (IPCC 2001). Climate change scenarios for Africa indicate future warming across the continent ranging from 0.2ºC per decade (low scenario) to more than 0.5ºC per decade (high scenario). This warming will be greatest over the interior of semiarid margins of the Sahara and central southern Africa (Desanker and Magadza 2001, Hulme *et al*. 2001). Over the next century this warming trend is expected to continue (Fig. 1) and be accompanied by a rise in sea level and increased frequency of extreme weather events (Hulme *et al*. 2001, IPCC 2007). However, the trend in annual precipitation indicates significant decline in rainfall over Africa. Among the ecosystems in the world that will be vulnerable to climate change impacts are forests, woodlands and coastal wetlands of Africa due to low adaptive capacity and large projected climate change impacts (Chidumayo *et al*. 2011). The distribution of the woody vegetation types of Africa is given in Fig. 2.

FIGURE 1 *Projected surface temperature changes for the period 2090–2099 relative to the period 1980–1999 (IPCC 2007)*



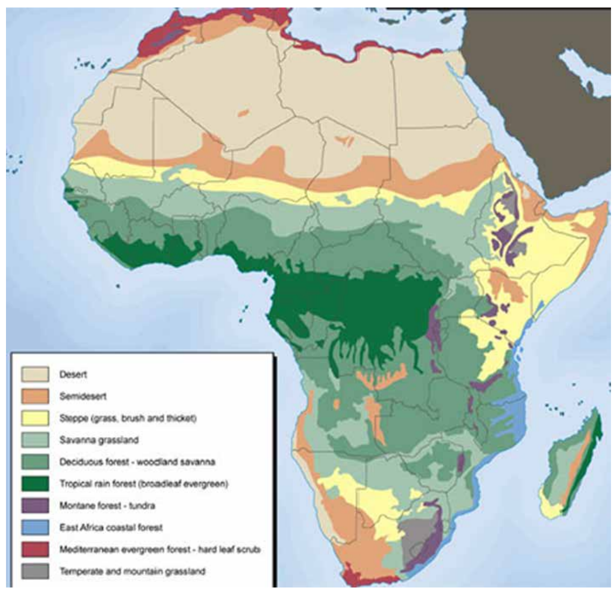
The issue of vulnerability has recently received great attention in climate change research and policy (Iyalomhe 2011, Medlyn *et al*. 2011). The definition of vulnerability to climate change by IPCC (2007) is adopted in this article. It refers to the degree to which forest ecosystems and social groups that depend on them are susceptible to, or unable to cope with, adverse effects of stress, including climate variability and extremes. This definition includes the sensitivity of the forest ecosystems and social groups once exposed to climate change and their adaptive capacity (IPCC 2007).

Few studies on climate vulnerability of biophysical systems have been undertaken in Africa. Likewise, most of information on this area is scattered and not yet compiled. This article therefore, attempts to give the review of available information on climate vulnerability of biophysical systems in forests, woodlands and coastal wetlands of Africa. This has a key role for future management of forest ecosystems for climate change mitigation and adaptation in Africa.

CLIMATE VULNERABILITY OF BIOPHYSICAL SYSTEMS IN MOIST TROPICAL FORESTS

Tropical moist forests are among the most vulnerable ecosystems to climate change variability and long term changes in temperature and rainfall (CIFOR 2007, IPCC 2007). The

FIGURE 2 *Map of Africa showing distribution of woody vegetation types*



climatic threats that make moist tropical forests vulnerable are discussed in detail hereunder.

Shift in species distribution

Many studies have indicated that distribution of the moist tropical forests will be increasingly affected by changes in precipitation and temperature from global climate change (Nicholson *et al.* 2000, Lewis 2005, IPCC 2007). Climate projections suggested that tropical most forests of West Africa had been facing declining trends of rainfall by 20–40% for the period between 1931–60 and 1968–90. The same declining trends were observed in mean annual precipitations in the tropical moist forests by 4% in West Africa, 3% in North Congo and 2% in South Congo for the period 1960–98 (Malhi and Wright 2004). On the other hand, tropical moist forests of Guinea were reported to experience the increase in annual rainfall by a 10% over the last four decades (Nicholson *et al.* 2000). Such changes in precipitation regime suggest that many of the tropical forests across West Africa will shift to drier regimes (IUFRO 2010). Furthermore, future change of precipitation is likely to cause tropical moist forests to develop into a dry deciduous type. With an increase of precipitation tropical forest would become an extra-equatorial rain forest (Muoghalu 2012a).

The projected increase in temperature is likely to lead to increased open water and soil-plant evaporation. The dominant impact of global warming as a result of increased potential evapotranspiration and decreased runoff will be a reduction on soil water. Salzmann and Hoelzmann (2005) pointed out that there is a critical threshold of water availability below which tropical forests cannot persist and are replaced by savanna systems. According to Lewis (2005) the moist tropical forests of Africa may shift to savanna if the current trends of global warming continue, leading to large carbon fluxes to the atmosphere. However, these results should be interpreted cautiously because currently it is very difficult to separate shift in distribution due to climate change and other factors (Lucier *et al.* 2009).

Changes in forest structure

Changes in plant growth rates due to changes in temperature and precipitation patterns associated with climate change are key determinants of future change in forest structure (IUFRO 2010, Gray 2011, Muoghalu 2012a). The moist tropical forests are currently experiencing significant structural changes, the most apparent of which is the increase in liana abundance and biomass (Schnitzer and Bongers 2011). That abundance of lianas is reported to be accelerated by high temperature raise and decrease precipitation associated with climate change in tropical countries (Michael and John 2007). Evidence of this has already been seen in moist tropical forests of West and Central Africa. Scientific evidence showed a linear increase in the percentage of species that were lianas in the moist tropical forests in Ghana, from 30% at a mean annual rainfall of 2000 mm per year to 43% at a mean annual rainfall of 1000 mm per year (Michael and John, 2007). Chave *et al.* (2008) reported that during a 10-year period from 1992 to 2002, liana abundance increased 1.8%, while tree abundance decreased 4.6% in the Congo Basin. Increase in liana abundance and biomass can be very detrimental to the structure of moist tropical forests through their influence on tree regeneration and growth (Moore 2010, MacKay *et al.* 2011, Kusumoto *et al.* 2013). Increase in liana abundance due to climate change impacts is likely to create additional challenges for livelihoods and management of moist tropical forests in Africa.

The projected rapid rise in temperature combined with other stresses, such as the destruction of habitats from land use change will lead to a net loss of about seven species of mammals by 2050, and 19 species by 2080 in Salonga National Park in the Congo Basin alone (Thuiller *et al.*, 2006). Many animals are essential in the reproductive processes of forest plants. The seeds of many forest plants are dispersed by animals and the seeds of certain species of trees must pass through the gut of an animal in order to germinate (Jordano *et al.*, 2007). Therefore, where frugivores become locally extinct due to climate change impacts and increased anthropogenic pressures, many tropical plants and trees that depend on animals will not be able to reproduce (Moore, 2000). This means that loss of mammals especially frugivores due to climate change impacts will likely cause structural changes of moist tropical forests (Buckley *et al.*, 2006). Tuxill (1998) observed that loss of elephants in African countries due to various reasons has led to a loss of reproductive ability in many valuable tropical tree species.

Increased susceptibility to disturbance

Moist tropical forests are not fire resistant and therefore they are likely to suffer significantly from increased fire frequency and intensity resulting from future climate changes (Moyer 2006). Macchi *et al.* (2008) predicted that climate change will alter the likelihood of increased wildfire incidents in tropical moist forest zones of Africa especially in deciduous forests where the dry season exceeds 3–4 months. Potential impacts of fire to moist forests include changes in composition, structure, regeneration and recovery potential (Gray 2011). Scientific evidence shows that incidence of fire has occurred in forest areas where it has not been observed in the past. Evidence of increased fire in forest areas are already seen in Angola, southern Democratic Republic of Congo and Central African Republic (Muoghalu 2012a). It was projected that fire incidences will increase in tropical moist forests of Africa due to rising temperature (Gray 2011). Furthermore, Jagtap and Chan (2000) and Muoghalu (2012a) have reported that increased human activities such logging have led to the replacement of afromontane forests found in the west of Cameroon and the east of the Democratic Republic of Congo to a variety of different land use types, patches of secondary forest and fallow vegetation, and small remnants of primary vegetation.

The structure and dynamics of tropical moist forest always reflect the complex interplay of disturbance events and regeneration process taking place through time and space (Chadzon 2003). After the moist tropical forest has been destroyed or disturbed by natural or anthropogenic factors such as fire, logging, hurricanes, tree falls or swidden agriculture, it begins a natural regeneration through a series of vegetational stages (Richards 1955, Swaine and Hall 1983). The rate of change of the forest structure and composition is strongly influenced by the nature and extent of residual vegetation in the form of resprouts, remnant trees and shrubs, seedling/saplings and/or the soil seed bank (Uhl *et al.* 1981, Galindo-Gonzalez *et al.* 2000, Elmqvist *et al.* 2001, Chadzon 2003). The remaining forests are also undergoing changes because of the alteration of the physical, chemical and biological environment that the species are adapted to due to climate change and variability.

Loss of biodiversity

Losses of biodiversity are closely linked to species extinction resulting from global climate change (Gray 2011). Cunningham and Read (2003) reported on greater mortality of certain tropical forest species due to increasing atmospheric temperature. IPCC (2007) confirmed that climate change is a major driver of biodiversity loss in tropical forests and several other ecosystems. It was estimated that on the average 15–37% of species will become extinct by 2050 and that climate-induced extinction rates in tropical biodiversity spots are likely to exceed the predicted extinction rates from deforestation by the end of this Century. One of the biggest losses will be forests along the Congo Basin, driven by increasing aridity and anthropogenic activities (Okali 2010). Increased forest fragmentation due to increased anthropogenic activities exacerbated by climate change is projected to reduce the probability of maintaining effective reproductive units of plant and animal populations in the moist tropical forests. Most tropical trees are pollinated by animals, insects, birds and other organisms. When a forest becomes fragmented, trees of many species are isolated because their pollinators cannot cross the unforested areas (Maarten *et al.* 1999). Under these conditions, the trees in the fragments will then become inbred and lose genetic variability and vigor (Malcom *et al.* 2002). Likewise, intensive hunting, by depleting animal populations, inhibits plant reproduction, since many seeds can neither be dispersed, nor flowers be pollinated. For example, tree in the Omphalocarpum genus in the Congo rainforest is dependent on elephant to survive (Beaune *et al.* 2013). Where these seed dispersers have been eliminated, tree species dependent upon animal dispersers may become locally extinct. This will have an effect on forest composition (Byers *et al.* 2001).

Changes in hydrologic regime

It was projected that global warming will cause to heat up the earth's average temperature by approximately 30°C by 2080 (IPCC 2007). The rising temperature due to climate change impact will have a major effect on hydrologic processes, and will likely impact the local amount of precipitation in Africa. An assessment by Beyene *et al.* (2013) revealed that climate change will have a clear impact on the hydrological cycle of the Congo Basin. The authors projected that impact of extreme rainfall especially the wet extremes will increase with climate change in the Congo Basin. The rainfall is expected to increase and as a result the run-off could increase up to 50%. Run-off and stream flow will especially increase in the wet season. This indicates that flood risks will increase significantly in the future throughout the Congo Basin. Floods will however increase more in the central and western part of the Congo Basin. However, the uncertainty in rainfall scenarios is much higher at the Northern, Southern and Eastern edges of the basin as some scenarios show reduction in rainfall particularly during the dry season.

The report by Scholze *et al.* (2006) suggested that increased temperature will increase evaporative losses of the major rivers of Central and West Africa (Niger and Senegal) that transverse semi-arid and arid land on their way to the coast. Riebsame *et al.* (1995) were of the opinion that this situation will have serious implications for water resources and regional development unless compensated by increased precipitation. Climate change has the potential to impose additional pressures on water availability and water demand in Africa (Bates *et al.,* 2008). By 2020, between 75 and 250 million people in Africa are projected to be exposed to increased water stress due to climate change. The impact of projected climate change on water resources across the continent is not uniform. Model projections of future precipitation have many uncertainties (Elshamy *et al.* 2009). These uncertainties make it difficult to meaningfully communicate the impact of climate change on the water resources and develop adaptation strategies.

CLIMATE VULNERABILITY OF BIOPHYSICAL SYSTEMS IN WOODLANDS AND SAVANNAS

Scientific evidence shows that climate change is already having an impact on the dynamics of African biomes including the woodlands and savannas and their biodiversity (Erasmus *et al.* 2002, Munishi 2012). Following are the climatic threats that make woodlands and savannas vulnerable.

Shift in species distribution

Global distribution of the miombo woodlands and savannas will be increasingly affected by climate change (Prowse *et al.* 2009, Gandiwa and Zisadza 2010, Dewees *et al.* 2011). With increase in precipitation and temperature miombo woodlands on well drained soils would develop into closed woodlands and evergreen forests while in severe cases miombo woodlands in areas with poorly drained soil would be replaced by wooded grasslands or thickets/bushlands (Munishi, 2012). Records show that under climate change scenario there is a climate shift towards reduced annual precipitation and high ambient temperatures in Zimbabwe. This change in climate was projected to cause warm temperate moist forest in north eastern Zimbabwe to be replaced by subtropical moist forest condition. Similarly, the south eastern region of Zimbabwe was projected to shift from subtropical moist forest area to subtropical dry forest life zone. The greatest life zone changes are those shifts from subtropical dry forest to tropical very dry forest and form subtropical thorn woodland to tropical very dry forest (Matarira and Mwamuka 1996).

The savannas may be shifting towards greater tree dominance as atmospheric carbon dioxide (CO_2) rises with diminishing grass suppression of faster growing tree saplings (Bond *et al.* 2003). The resulting more densely forested landscape, whilst beneficial for biomass and carbon storage, will be deleterious to wildlife. This could cause extinction of species with limited distribution range and poor dispersal abilities. The decline in rainfall in West Africa from 1970s to 1990s has caused a 25–35 km southwards shift of the Sahelian, Sudanese and Guinean ecological zones in the 20th century. This has resulted in loss of animals, decline in tree species in the Sudanese, Guinean and Sahelian and shifting sand dunes in the Sahel with negative consequences for crop and livestock production and the rural communities that depend on agriculture for their livelihoods (Gonzalez 2001, IFAD 2011).

Global warming could change the amount of rainfall that savannas receive each year. The dry season might be eliminated, causing the amount of trees and shrubs to overtake the grassland. Significant increase in rainfall will cause trees to overtake the vegetation of savannas and become tropical rain forests. Stable savannas receive less rain per year, which limits tree growth and allows the grass to grow. Unstable savannas receive more annual rain, but the dry seasons helps balance the amount of tree growth. Fire and animal grazing in the grasslands also helps control the amount of new trees. Without the balance between grassland and trees, the food supply of several animal species might be affected. Some of these species include elephants, giraffes and lions. These animals might be forced to find new habitats to survive. There is the chance that they will not all be able to locate an adequate food supply and would face potential extinction (Muoghalu 2012b).

Changes in vegetation structure

Rising temperature due to climate change is likely to reduce fruit and seed production in African woodland trees with negative consequences for plant genetic diversity. Flowering, pollination, seed production, fruit and seed development periods and seed germination might be affected by climate change impacts (Munishi 2012). Chapman *et al.* (2005) observed that in East and Southern Africa fruiting levels will be negatively affected by rising temperature. For example, a negative correlation between the proportion of fruiting trees in Kibale National Park, Uganda, and minimum temperature has been observed. Similar observations have been made concerning fruit production in *Strychnos spinosa* in Lusaka, Zambia (Chidumayo 2011). A study conducted in savanna woodland trees in central Zambia confirmed that rising temperature to 1ºC significantly affected seedling emergence and increased mortality (Chidumayo 2008, 2011).

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 forest may be more sensitive than grasslands or savannahs to reduced precipitation (Hely *et al.* 2006). 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. 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).

Increasing atmospheric CO_2 concentration has the potential benefits of changing climate in terms of increasing the growth rate of forest trees (Gray 2011). The increasing CO_2 will result in increased tree growth and woody thickening which will allow trees to grow above a threshold (Rohde *et al.* 2006). Furthermore, Ainsworth and Long (2005) have reported that trees and shrubs show higher CO_2 responsiveness than do herbaceous forms. However, fire limits tree growth and has a pronounced influence on the amount of biomass burned (Muoghalu 2012b).

Invasive species

Climate change may promote growth of invasive species and increases the risk of extinction of existing species with narrow geographic or climatic distributions (Munishi, 2012). A study done by Malcolm *et al*. (2002) shows that invasive species and other species with high fertility and dispersal capabilities are highly adaptive to variable climatic conditions. Due to its climate sensitive native tree species in miombo woodlands of East Africa may be particularly vulnerable to invasive species colonization. For example, in Tanzania two species have been largely reported as weedy or invasive: *Senna spectabilis* or Cassia (Wakibara and Mnaya 2002) and the White thorn (Obiri *et al*., 2010). Evidence shows that these species tend to suppress the growth of native trees, shrubs and grasses growing beneath or close to them. Subsequently foliage for wildlife animals tends to be reduced resulting to starvation and death of the animals.

Loss of biodiversity

Miombo woodlands and savannas are one of the forest ecosystems in Africa vulnerable to severe droughts (Muoghalu 2012b). Some models predict that global warming could cause increased periods of drought in some miombo woodlands and savannas of Africa. Droughts in the woodlands and savannas especially in the Sahelian zone have become more frequent since the late 1960s (Muoghalu 2012b). Bowman (1993) warned that severe droughts could destroy the savannas vegetation and cause several species to become extinct. The more important risk from severe drought is that of mortality, which threatens viability of miombo woodlands and savannas. Severe drought could cause mortality through several alternative mechanisms including hydraulic failure where by stems can no longer transport water and carbon starvation which can cause insufficient photosynthesis because stomata are closed. Drought stress can also predispose trees to pests and diseases, which may be the ultimate cause of mortality. A decrease in vegetation might lead to famine and the loss of a suitable habitat for the animals that reside in the savannas (McDowell *et al*. 2008). Domestic livestock mostly eat grass in miombo woodlands and savannas. Therefore, changes in tree cover will impact livestock production by decreasing livestock carrying capacity as a result of suppressive effects of trees on grass production in the woodlands and savannas. The change could affect the physiology of the plants and thereby adversely affecting their survival, and worse still could also reduce the population of the frugivorous animals and birds that feed on them. An increase in the frequency of drought in the biomes has resulted in episodic die-off of woody vegetation and resulted in degradation. For instance, some species such as *Adansonia digitata, Diospyrosme spiliformis* and *Anogeissus leiocarpusj* valuable for non-timber forest products in Burkina Faso have become extinct which is attributed to recurrent droughts (Idinoba *et al*. 2009).

Changes in animal behaviour

With reference to animal species and climate change, weather extremes can affect biodiversity in more complex ways (Munishi 2012). For instance, in African elephants (*Loxodonta africana*) common in most of the woodlands of southern and eastern Africa, 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 (Rubenstein 1992).

Changes in the hydrologic regime

One of the most important aspects of miombo habitat is its ability to regulate the hydrology of the surrounding woodlands and their associated waterways and wetlands. Increased deforestation due to natural and anthropogenic forces has led to a loss of woody cover, which has affected the hydrologic regime that supplies water to the seasonal wetlands that are interspersed throughout the woodlands. For example, Lake Chad which is strategic for global biodiversity, being home to 120 species of fish as well supporting 372 bird species has changed from open water to marshy environment and about 50% of wetlands have been lost. The impact of this phenomenon is most felt in the collapse of some fisheries and recessional rice cultivation, as well as sedimentation in rivers and other water bodies, which led to the colonization of the silted sites species: Typha grass as a major problem and quelea birds as invasive pests prevalent all over the basin (Tiega 2010). Changes to the biodiversity of these ecosystems due to climate change may be aggravated by other human-induced changes in the natural environment adversely affecting the goods and services they provide to the communities that depend on them.

CLIMATE VULNERABILITY OF BIOPHYSICAL SYSTEMS IN COASTAL WETLANDS

Coastal wetlands, which are comprised of mangroves, swamps, marshes and other coastal plant communities, provide a large number of goods and services that contribute to the economic welfare of the local and global communities (Millennium Ecosystem Assessment 2005). African coastal wetlands are among the ecosystems most vulnerable to the impacts of climate change. The main impacts are likely to be caused by increasing temperature, changing precipitation regimes, rising sea level, increasing tropical storm magnitude and frequency, and increasing CO_2 concentration (Alongi 2008). Sea level rise is the greatest climate change challenge that coastal wetlands will face (Field 1995). The projected impacts of sea level rise to coastal wetlands are alteration of inundation period, erosion and salt water intrusion (Ellison and Stoddart 1991, McKee 2004, Nicholls *et al.* 2007). Such impacts are projected to affect health of coastal wetlands due to changes in salinity, recruitment, inundation, and changes in the wetland sediment budget (Gilman *et al*. 2006). A study done in Cameroon to assess vulnerability to climate change of mangroves proved that sea level rise is causing mangrove mortality (Ellison and Zouh 2012). This means that although mangrove trees are adapted to grow in salt water, they require regular flushing with freshwater. They will die if immersed in saltwater all the time. *Rhizophora mucronata* and *Bruguiera racemosa* are species that do not have a high tolerance to changes in salinity levels. *R. mucronata* requires large inputs of fresh water (Clausen *et al*. 2011).

Landward migration of mangroves is a complementary natural adaptive response to sea level rise (McLeod and Salm 2006, Taylor *et al*. 2010). However, the success of this response depends on the availability of habitat with suitable hydrology, sediment composition, absence of competitive species, and the possibility of waterborne recruitment for mangrove species (Ellison and Stoddart 1991, Clausen *et al*. 2011). In areas where the landward margins of mangrove systems are already at boundaries of steeply elevated land or barriers constructed by man like dikes, roads, urban developments, or agricultural fields, there will indeed be constraints on inland migration of mangroves (Kjerfve *et al.* 1994, Roth 1997). Many studies have indicated that mangroves in Africa are unlikely to migrate landward because of human encroachment at the landward boundary, and the width of mangrove systems is likely to decrease under a regime of relative sea level rise (McLeod and Salm 2006, Popoola 2012).

Increased precipitation due to climate change can flood coastal wetlands and may cease them to be exposed, reducing the feeding grounds of many species of water birds. Such a situation may prevent migratory birds from building up sufficient stores of energy to allow their annual migration to breeding grounds (Galbraith *et al.* 2002). Similarly, flooding caused by increased precipitation may result in decreased survival of mangroves. The El Nino rains that occurred from 1997–98 caused massive death of mangroves in Kenya due to flooding. The loss of mangrove species will have devastating economic and environmental consequences for coastal communities, especially in those areas with low mangrove diversity and high mangrove area or species loss. Adaptive capacity was improved by planting appropriate mangrove species in the area affected by El Nino rains (Kitula 2012a). This means that in case of climate change, loss of some mangrove species can be compensated by planting them although overall loss cannot be recovered.

Scientific evidence shows that coastal wetlands will suffer increasing salination due to high tides and storm surges that are projected to bring saltwater inland, causing the death of plants that cannot tolerate brackish water and, subsequently, of the animals that depend on those plants. This salination will affect not only coastal biodiversity, but also ecological processes and primary and secondary productivity with adverse impacts likely for local communities who depend on wetland resources (McLeod *et al*. 2005).

Increased incidence of human disturbances in coastal wetlands in Africa is one of the negative impacts associated with climate change. For example, many mangroves in African countries are subjected to the over-extraction of timber and NTFPs as well as to unsustainable fishing and wildlife use, driven the need to meet daily needs (Kitula 2012b, Popoola 2012). Such over-use leads to degradation of the mangrove resource and, in some cases, its complete removal (Din *et al.* 2008). This is evident from the analysis of the most recent satellite images combined with ground truth observations in Africa. For instance, in Cameroon analysis of spatial change from 1975 to 2007 showed that there had been an overall decline of 5% in mangrove area due to increased pressure on the forest resources for fuelwood (Ellison and Zouth 2012). In Tanzania, results from satellite images shows that mangroves area are converted to other land use like rice farming, salt pans, mariculture and settlements (Wang *et al*. 2003, Kitula 2012b).

Report by Popoola (2012) shows that pollution derived from single or multiple sources including industry, sewage, dredging, pond effluent, agricultural and urban runoff and involving pollutants such as solid wastes, toxic chemicals, hydrocarbons and persistent organic materials can lead to the loss of biodiversity, declines in wetland productivity and, in extreme cases, complete destruction. Upstream activities such as dam construction, water diversion and deforestation alter the flow regimes of freshwater into mangrove ecosystems, often causing marked reductions, especially in dry seasons and arid environments. For example, the construction of the Cahora-Bassa dam on the Zambezi River has reduced the flow of water, altering water conditions in the mangroves and ultimately causing a shrinking of mangrove area (Taylor *et al*. 2010).

Coastal modifications such as the construction of sea walls, ports and dredging can also alter tidal circulation patterns, which in turn, can lead to structural and functional changes. Concern about mangrove loss is highly variable, but a few countries in West and Central Africa like Guinea-Bissau, Nigeria, Cameroon and Gabon have created networks of protected areas that include mangroves. In some cases, considerable effort has been made to involve local communities and garner broad supports, but sustainable use of mangroves is encouraged (FAO 2005).

CONCLUSION AND RECOMMENDATIONS

Climate vulnerability of biophysical systems in forest ecosystems depends on amount of damage experienced by a forest type caused by the impacts of a specific type of hazard and it is therefore a function of the frequency and severity of a given types of hazards (Brooks 2003). There is compelling evidence that climate has changed considerably over the past two centuries in Africa and this is demonstrated by increasing mean temperature observed over time, and increased occurrence of forest fires. Future projections indicate that these impacts are likely to worsen over time and pose great threats to natural resources and biodiversity in forest, woodland and wetland ecosystems in Africa. However, these projections should be interpreted cautiously because currently it is very difficult to separate for example shift in distribution due to climate change and other factors. Yet still, the outcomes of interacting factors such as temperature increase, variability in precipitation, extreme weather events, CO_2 fertilization, increase and intensity of wildfires in forests and woodlands of Africa are uncertain. Therefore, more research should be carried out on impacts of climate change on forests and woodlands of Africa, especially, on individual trees, species composition, functional groups, growth, phenology and regeneration for developing appropriate mitigation and adaptation strategies to climate change. Likewise, climate change should be considered in the management of forests, woodland and coastal wetlands through developing management plans to deal with impacts.

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