A PLATFORM FOR STAKEHOLDERS IN AFRICAN FORESTRY

CLIMATE VULNERABILITY OF BIOPHYSICAL AND SOCIO-ECONOMIC SYSTEMS IN WOODLANDS AND SAVANNAS IN EASTERN AND SOUTHERN AFRICA

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Climate vulnerability of biophysical and socio-economic systems in woodlands and savannas in Eastern and Southern Africa

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Acronyms and abbreviations

AFF	African Forest Forum
AMCEN	African Ministerial Conference on Environment
CBD	Convention on Biological Diversity
CBNRM	Community Based Natural Resource Management
CERES	Crop Environment Resources Synthesis Model
CIMMYT	International Maize and Wheat Improvement Centre
COMESA	Common Market for Eastern and Southern Africa
DRC	Democratic Republic of Congo
EAC	East African Community
ENSO	El Niño Southern Oscillation
FAO	Food and Agricultural Organization of the United Nations
GCM	General Circulation Models
GDP	Gross Domestic Product
GHG	Green House Gases
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
IRA	Institute for Resources Assessment (UDSM, Tanzania)
IUCN	International Union for Conservation of Nature
LULUCF	Land Use, Land Use Change and Forestry
MDG	Millennium Development Goals
NAFORMA	National Forest Resources Assessment Programme
NDVI	Normalised Difference Vegetation Index
PSPs	Permanent Sample Plots

REDD	Reduced Emissions from Deforestation and Forest Degradation
SADC	Southern African Development Community
SUA	Sokoine University of Agriculture (Tanzania)
UDSM	University of Dar es Salaam
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World-Wide Fund for Nature

Executive summary

Climate change is a major threat to achieving the poverty reduction aspirations of many African countries as well as to the attainment of the Millennium Development Goals (MDGs). It is affecting rainfall patterns, water availability, sea levels, the dynamics of droughts and bushfire frequency. These are increasingly impacting woodland ecosystems, associated livelihoods, human health, agriculture productivity and biodiversity (Munishi et al., 2010; Kowero, 2011). Climate change will therefore adversely affect livelihoods, national incomes and the environment. While woodlands are affected by climate change, they also play key roles in mitigation and adaptation to climate change. These roles may include increasing the resilience of rural communities to climate change and support to species to adapt to changing climate by acting as refuge during adverse climate conditions. Woodlands also indirectly support economies to adapt to climate change by reducing costs of climate-related negative impacts, through provision of goods and services during extreme weather events, and by providing key assets for reducing vulnerability to the effects of climate change. Woodlands play a major role in climate change mitigation as deforestation and forest degradation is estimated to contribute to about 18% of the global carbon dioxide (greenhouse gas - GHG) emissions and have considerable potential to mitigate emissions through carbon sequestration. The major objective of this work was to review available information on climate vulnerability of biophysical (i.e. soil, water, and biological resources) and socio-economic (i.e. human health, livelihoods, products, trade and development) systems in woodlands of Eastern and Southern Africa.

The woodlands of Eastern and Southern Africa are of various types including Miombo Woodlands covering about one-third of the region, *Terminalia-Combretum* savannah woodlands, Mopane woodland and Zambezi Teak (*Baikiaea plurijuga)* woodland. Further the *Acacia-Combretum* woodlands in Zimbabwe and *Acacia–Commiphora* woodlands in Kenya and Tanzania form major woodland types. The Miombo ecosystem is one of the tropical wildernesses in the world covering about 3.6 million km^2 and spanning ten countries in East, Central and Southern Africa (Munishi et al., 2011).

Climate change will have wide-ranging effects on the environment, and on socio-economic and related sectors, including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity, woodlands inclusive. The woodlands of Eastern and Southern Africa will be responding to variable rainfall in terms of seasonality and amounts with predominantly decreasing rainfall and increasing temperatures (Munishi et al., 2010). Climate change scenarios for Africa include higher temperatures across the continent estimated to be increasing by 0.2°C per decade (Elagib and Mansell, 2000) and more erratic precipitation. Changes in rainfall patterns are likely to lead to severe water shortages

and/or flooding while temperature increases will potentially severely increase rates of extinction for many habitats and species (up to 30 per cent with a 2°C rise in temperature).

Water-related problems, already serious in the region, are likely to worsen as a result of climate change (AMCEN, 2011). Intense rainfall events will increase the incidence of flooding in many areas. At the same time, reduced run-off will exacerbate water stress and reduce the quality and quantity of water available for domestic, crop and livestock use. In a wider context the predicted impacts of climate change on water resources in woodlands of Eastern and Southern Africa indicate that by 2020, between 75 and 250 million people are projected to be exposed to increased water stress. Agricultural production, including access to food, in many Eastern and Southern African countries is projected to be severely compromised due to water scarcity which will further adversely affect food security and exacerbate malnutrition.

The woodlands of Eastern and Southern Africa are diverse and such diverse vegetation would imply a variety of habitats and areas of high species diversity and endemism. Climate change impacts on the woodlands in this region will thus likely impact biodiversity and vulnerable endemic species. Major impacts of climate change on the woodlands include changes within some types and disappearance of others, and changes in species composition. Because climate is a primary determinant of species distributions and ecosystem processes, new climates may promote formation of new species associations and other ecological changes whereas changes in current climates may also increases the risk of extinction of species with narrow geographic or climatic distributions and disruption of existing communities.

Eastern and Southern African woodlands are critical for the well-being of people and the provision of a broad range of products, services and functions. In the region they contribute immensely to economic and social development through formal and informal trade in timber and non-timber forest products; to environmental services through their safety net, spiritual and aesthetic value and, protection to water sources and storage of considerable amounts of carbon.

The public health effects of global warming in Eastern and Southern Africa will likely be related to rising temperatures, severe water shortages and extreme events, such as frequent and severe droughts, floods and storms. Climate change impacts agriculture and food security through water supply, occurrence of extreme natural hazards, mobility and occurrence of infectious diseases, all of which have consequences on health. Human health in the Eastern and Southern African woodland regions will likely suffer from increase in the incidence of diseases. Several health hazards related to climate change have already been reported in Tanzania, including malaria, which has spread to non-traditional areas, dysentery, cholera, meningitis, typhoid, malnutrition and trachoma. Water-related diseases, such as schistosomiasis, cholera and other gastrointestinal diseases are likely to increase.

Severe shortage of food and increase in the rate of malnutrition, especially among children, will intensify.

The predicted scale of the changes in climate will have a devastating impact on agricultural production systems that are already struggling to meet household needs and provide the engine of growth that the region so badly needs. Such changes will also impact on the dynamics of livelihoods associated with the use of the woodlands. This will have significant impacts on total livelihoods and the resilience of people to climate-based shocks and for many people in Eastern and Southern Africa, the loss of woodlands and the goods and services that they provide reduces their livelihood options, especially in times of stress.

The woodlands, on the other hand, are also important in mitigating and adapting to climate change through their influence on the water cycle, carbon sequestration and storage. It has been estimated that stem carbon stocks in the woodlands of Mozambique amount to 19.0 (+/- 8) $t.ha^{-1}$, while the carbon stock in undisturbed woodland soils is c. 58 $tC.ha^{-1}$, of which about 13 $tC.ha^{-1}$ are lost when the woodlands are converted to agricultural land. Regenerating woodland can recover lost carbon at a rate of 0.7 $tC.ha^{-1}$ per annum on land that is abandoned for agriculture. In Tanzanian miombo woodlands, the carbon stocks have been estimated to range from below 15 $t.ha^{-1}$ to c. 30 $t.ha^{-1}$, with different tree parts and species contributing differently to this carbon pool. Given the extent and diversity of the woodlands in the region the potential contribution to mitigation and adaptation to climate change is high.

Most of the permanent sample plots (PSPs) in Zambia seem to have been degraded while some remain intact or relatively undisturbed. Given the fact that the baseline information from such plots exists they can be used for generation of data and information for future monitoring of the dynamics of the ecosystems and for REDD+ purposes. However, some modifications may be needed to make them more suitable monitoring sites for REDD+, especially with regard to acquiring more data on carbon pools that need to be monitored according to IPCC requirements. For example, plots in Southern Africa were established for monitoring biodiversity and not for carbon and would require additional protocols for assessing carbon stocks.

The plots in Tanzania were established for the purpose of monitoring mainly carbon. However, other ecosystem parameters, such as regeneration, may only be inferred, as they do not seem to have been assessed adequately. In this respect additional information may be required in order to monitor other parameters.

Generally, all available plots are suitable for monitoring future changes in the ecosystem as well as monitoring for REDD+. Monitoring changes over time and establishing changes in carbon stocks over time is an important process in REDD+ that would show additional benefits of carbon projects.

On institutional arrangements for the sustainable management and monitoring of the plots, four options are suggested, viz.:

1) the work will be done by the institutions that established the plots in the first place as they would be the best suited to continue monitoring the plots in order to ensure consistency of the information collected;

2) use academic, training and research institutions in forestry where there is a substantial determined and scientific labour force from students who undertake research using the PSPs and thus a good avenue for capacity building in generating long term data on forests, carbon and MRV;

3) where the two approaches are not feasible then the Forestry Research Institutions in a country would be given the task although they may require capacity enhancement/training on the different approaches that have been used by the different institutions to ensure consistency in data; and,

4) a more general approach where initially the work would be done by the institutions that established the plots while building the capacity of Forestry Research Institutions in the different approaches for monitoring forest growth and MRV then let the research institutions take the lead and work in collaboration with academic, training and research institutions.

CHAPTER 1 Introduction

Climate change is recognised as a major threat to achieving the poverty reduction aspirations of many African countries as well as the attainment of the MDGs. Climate change is affecting rainfall patterns, water availability, sea levels, droughts and bushfire frequency, increasingly impacting on human health, agriculture productivity and biodiversity (Munishi et al., 2011). Climate change and climate variability (or unpredictability) is a challenge that already faces all the countries in Eastern and Southern Africa (ESA). The Intergovernmental Panel on Climate Change (IPCC), in its Third Assessment Report (AR3) in 2001, alerted the World to the unavoidable impacts of climate change in the near term and raised the need to cope with climate change impacts through adaptation. In particular, it pointed out that poor countries would be more vulnerable and need assistance to adapt. Further, the IPCC in 2007 confirmed in its Fourth Assessment Report (AR4) that there was *"new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities such as land use".* The land use sector, including forestry and agriculture, is an important source of anthropogenic greenhouse gas (GHG) emissions. Land use change, mainly deforestation, contributed about 20% of the GHG emissions from anthropogenic sources between 1989 and 1998 (IPCC, 2000 and 2007). When adding all emissions from the *land use, land use change and forestry* (LULUCF) sector the share is over 30%.

It is a growing recognition and concern that the accumulation of greenhouse gases in the atmosphere will have a significant impact on climate. Different parts of Africa may be impacted differently and in the Eastern and Southern African region, climate change effects include increased frequency of extreme weather events, flooding, storms, and droughts. These developments will potentially have significant, social, economic and political impacts, including effects on food production and water availability, which pose serious threats to the region's food production systems and its progress towards poverty reduction. The nature and extent of climatic changes not only hinders human development and environmental conservation, but also forms a major threat to human security at regional and national levels. Climate change may also spark conflict between and within nations as resources become scarcer and disasters destroy livelihoods. It will therefore adversely affect livelihoods, national incomes and the environment.

While woodlands are affected by climate change, they also play key roles in mitigation and adaptation to such change. These roles may include increasing the resilience of rural communities to climate change, and support to species to adapt to changing climate by acting as refuge during adverse climate conditions. The woodlands of Eastern and Southern Africa also indirectly support economies to adapt to climate change by reducing the costs of climate-related negative impacts and through provision of goods and services during extreme weather events and are therefore key assets for reducing vulnerability to the effects of climate change. Woodlands also play a major role in climate change mitigation as deforestation and forest degradation is estimated to contribute to about 18% of the global carbon dioxide (greenhouse gas - GHG) emissions and have considerable potential to mitigate emissions through carbon sequestration. Woodland management activities can therefore contribute to mitigation that can be achieved through reforestation, forest restoration and changes to forest management practices (Munishi et al., 2011).

CHAPTER 2 Woodlands of Eastern and Southern Africa

The woodlands of Eastern and Southern Africa are of various types including Miombo Woodlands covering about one-third of the region (Munishi et al., 2011), *Terminalia-Combretum* woodland savannahs, Mopane woodlands and Zambezi Teak (*Baikiaea plurijuga)* woodlands. Further, the *Acacia-Combretum* woodlands in Zimbabwe and *Acacia–Commiphora* woodlands in Kenya and Tanzania form major woodland types. Based on the Holdridge life zones (Matarira and Mwamuka, 1996), the woodlands in Zimbabwe consist of subtropical dry forest, subtropical thorn woodland and tropical very dry forest. The Holdridge life zone subtropical dry forest covers the largest area in Zimbabwe (68.7% by area) and extends across the largest latitudinal range, 15.5"S and 22"S. This zone corresponds to miombo woodland, Mopane woodland, *Terminalia-Combretum* woodland, Zambezi teak (*Baikiaea plurijuga*) woodland and Acacia woodland according to historic classification systems (Matarira and Mwamuka, 1996).

The Miombo ecosystem is one of the world’s tropical wildernesses covering about 3.6 million km^2 and spanning ten countries in East, Central and Southern Africa (Munishi et al., 2011). It forms dense forest woodlands that bisect Africa directly south of the Congo Basin and the East African savannahs. It stretches all the way from Angola in the west to Tanzania in the east. These woodlands are dominated by trees of the subfamily Caesalpinioideae, particularly species belonging to the genera *Brachystegia, Julbernardia* and *Isoberlinia*, which seldom occur outside Miombo (Campbell, 1996). Much of the area covered by this eco-region overlaps with White’s (1983) floristically impoverished drier Zambezian Miombo woodland. The vegetation of this area is primarily the same woody species but not growing as dense and thereby permitting a well-developed underlying layer of grass.

The dominance of one family of trees provides the unifying feature for this ecosystem (Frost, 1996; Chidumuyo, 1997; Timberlake, 2000; WWF, 2001; Byers, 2001). The Miombo ecosystem contains and partly overlaps with a diversity of major woodland types, including wet Miombo, dry Miombo, *Burkea-Terminalia* woodlands, *Baikiaea* woodland, Mopane woodland, *Acacia-Combretum* woodland, dry evergreen forests (Cryptosepalum), wetland grasslands and thickets (Itigi thicket) (Byers, 2001; Munishi et al., 2011). Dominant tree species include *Brachystegia spiciformis*, *B. boehmii, B. allenii* and *Julbernardia globiflora* (Campbell et al., 1996).

In areas of higher rainfall, a transition to wetter Zambezian Miombo occurs (White, 1983). This vegetation supports greater floral richness and includes almost all the Miombo dominants, such as *Brachystegia floribunda*, *B. glaberrima*, *B. taxifolia*, *B. wangermeeana*, *B. utilis*, *Marquesia macroura*, *Julbernadia globiflora*, *J. paniculata* and *Isoberlinia angolensis*. Deciduous riparian forest lines the numerous rivers in the area, while dry forest and thicket associations are also found in the ecoregion, especially in rocky places. The Miombo ecosystem is composed of three major eco-regions which include the eastern Miombo woodlands (AT0706), the Angola Miombo woodlands (AT0701) and the Central Zambezian Miombo woodlands (AT0704). The eastern Miombo woodlands eco-region covers an area of about 483 900 km² and consists of a relatively unbroken area covering the interior regions of South-Eastern Tanzania and the northern half of Mozambique, with a few patches extending into South-Eastern Malawi. The eco-region experiences a seasonal tropical climate with most rainfall concentrated in the months from November through March followed by an intense drought that can last up to six months. Mean annual rainfall ranges between 800 and 1 200 mm, although peaks of up to 1 400 mm per annum are found along the western margins.

The Central Zambezian Miombo woodland eco-region covers an area of 1 184 200 km² and lies beyond Lake Malawi to the west. The Zambezian and Mopane woodland Eco-region lies to the south. This eco-region covers about 70% of Central and Northern Zambia, the South-Eastern third of DRC, Western Malawi, much of Tanzania and parts of Burundi and North-Eastern Angola. Consisting mainly of broadleaf, deciduous savannahs and woodlands, it is characteristically interspersed with edaphic grassland and semi-aquatic vegetation, as well as areas of evergreen groundwater forest. The extensive Angolan Miombo woodlands (660 100 km²) are part of an even larger Miombo ecosystem that covers all of Central Angola and extends into DRC. This eco-region comprises moist, deciduous broadleaf savannahs and woodlands interspersed with areas of edaphic and secondary grasslands. It forms the westernmost part of the large Miombo woodland belt that is the dominant type of savannah woodland in the Zambezian centre of Endemism (White, 1983; Campbell, 1996; Munishi et al., 2011). Most of the Angolan Miombo woodland is found at elevations between 1 000 and 1 500 m above sea level. The mean annual rainfall in the eco-region ranges from less than 800 mm in the south to about 1400 mm in the north and west (Huntley *et al.,* 2006). The region is home to at least 4 500 endemic plant species and 163 endemic animal species. It is a centre of diversity for underground trees (i.e. with stems growing underground) - of the 98 species known from Africa 86 are confined to this region. The Miombo ecosystem is also a globally important carbon store. It is an area where humans have coevolved with wildlife over millions of years and contains about 23 and 29% of the world's black and white rhino populations, respectively, 42 to 45% of Africa's elephant population, most surviving wild dogs, and over 66 million people with different livelihoods (White, 1983; WWF, 2001; Byers, 2001; Campbell, 1996; Rodgers, 1996).

The *Acacia–Commiphora* woodlands extend from Somalia into Kenya and to the southern-most extent in Tanzania's Iringa region. This woodland type forms a Phytochoria referred to as the Somali–Masai Regional Centre of Endemism (White, 1983). It is dominated by the genera *Acacia* and *Commiphora* with some elements of *Combretum* and *Balanites*. The Somali-Masai Region is moderately rich with around 2 500 species of flowering plants of which around 50% appear endemic to the region (Linder et al., 2005).

Specific plant associations also occur in specific locations among the major vegetation types. Munishi et al. (2011) identified six plant communities with unique composition in the miombo woodlands of Tanzania, each one responding to a multitude of environmental factors including topography, slope and soil moisture. They include the following types of woodlands: *Combretum molle / Sclerocarya birrea / Combretum zeyherii / Acacia seyal var. fistula; Brachystegia bussei / Pterocarpus tinctorius; B. microphylla / Isoberlinia tomentosa / Hymenocardia acida / Syzygium owariense; Bridelia cathartica / Diospyros espiliformis; Brachystegia boehmii / Pericopsis angolensis;* and *Julbernardia globiflora* woodland.

CHAPTER 3 Climate Conditions to which the Woodlands are responding

The woodlands of Eastern and Southern Africa will be exposed to variable rainfall in terms of seasonality and amounts, with decreasing rainfall and increasing temperatures predominant (Munishi et al., 2010). Climate change scenarios for Africa include higher temperatures across the continent estimated to be increasing by 0.2°C per decade (Elagib and Mansell, 2000) and more erratic precipitation with slight increase in ecozones of Eastern Africa and moist forest ecozones of West Africa and sustainable declines in the productivity in the Sahel and in ecozones of Southern, Central and Northern Africa (Stige et al., 2006). This projection is in part reinforced by changes in rainfall over the last 60 years that has declined by up to 30% (Sivakumar and Motha, 2005), with the greatest negative impacts felt in the Sahel of West Africa (Nicholson, 2000; Hulme et al., 2001).

According to Chidumuyo et al. (2011) and Opere et al. (2011), as elsewhere in the world, an increasing trend in surface mean temperature has been observed for the African region using historic climate data. Although these trends seem to be consistent over the continent, the changes are not always uniform. For instance, decadal warming rates of 0.29°C in the African woodlands (Malhi and Wright, 2004) and 0.1°C to 0.3°C in South Africa have been observed. In South Africa and Ethiopia, minimum temperatures have increased slightly faster than maximum or mean temperatures. Between 1961 and 2000, there was an increase in the number of warm spells over Southern and Western Africa, and a decrease in the number of extremely cold days. In Eastern Africa, decreasing trends in temperature from weather stations located close to the coast or to major inland lakes have been noted. This trend is expected to continue and even to increase significantly. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), a medium-high emission scenario would see an increase in global annual mean surface air temperatures of between 3°C and 4°C by 2080.

The climate of Tanzania is diverse and variable depending on location and there have already been considerable changes in climatic or weather patterns over the country. Annual precipitation on Mount Kilimanjaro decreased by 150 mm between 1880 and 1900, indicating a lapse rate of 7.5 mm/year in this period. Annual rainfall figures from Lyamungo Research Institute since 1935 show a decreasing trend. Similarly, there has been a predominant decreasing trend in rainfall in the East Usambara Mountains .for the period 1921–2000 and in the Uluguru Mountains for the period 1933–2002.

Analyses of rainfall data from specific stations in Tanzania (Munishi et al., 2008) show a great variability in trends. Among zones showing decreasing rainfall in the March to May wet season are the southern highlands zone (Mbeya, Iringa, Ruvuma and Sumbawanga regions), where most of the Miombo woodlands are located, and the northern zone (Kilimanajro, Arusha regions), where the *Acacia–Commiphora* woodlands are dominant. On the other hand the total annual rainfall in the coastal zone seems to have been constant. This indicates that most of the zones where woodlands are located in Tanzania have experienced decreasing rainfall in the wet season with a big bearing on the climate conditions of these areas.

The unimodal rainfall zone, where the major rainy season is in October to December, extends from southern Tanzania (Iringa, Mbeya, Ruvuma, Rukwa) into the Southern African region (Malawi, Zambia Zimbabwe and Mozambique) where most of the Miombo woodlands are located, and show decreasing rainfall trends. This is likely to continue under the predicted climate change scenarios for the region. The number of rain days in most parts of Tanzania also shows a decreasing trend meaning that the growth season has shortened in most parts. Also, the date for the onset of rains seems to occur later and cessation dates come earlier, meaning that rainfall starts late and ends earlier in the woodland zone of the region, which is an indication of a shift in the growing season. The scenarios developed from General Circulation Models (GCM) have also indicated that there will be increased rainfall in some parts of the region while other parts will experience decreased rainfall. As the case for Tanzania, areas with two rainfall seasons (in the N part) would experience increase in rainfall for both seasons ranging from 5 to 45 %, while areas receiving unimodal rainfall, i.e. in the South, South-Western, Western, Central and Eastern parts of the country will experience decreased annual rainfall ranging between 5 and 15 % (Munishi et al., 2008).

An assessment of temperature patterns in 12 different climatic zones of Tanzania (Munishi et al., 2008) show that both maximum and minimum temperatures have increased in almost all the stations except in Central Tanzania where the mean maximum and minimum temperatures declined and in the southern highlands where the July mean minimum temperature decreased. There is therefore a general increase in temperature of 1°C–2°C all over the country.

Scenarios developed using General Circulation Models (GCM) predicted the mean daily temperature to rise by 3.5°C throughout the country, a rise that will be more pronounced during the cool months of June, July and August than during the warm months of December, January and February. The increase in annual temperature over the whole country is predicted to be between 2.5°C to 3.0°C in the warmest months of December and February and between 3.0°C to 3.9°C in the coolest months of June-August.

According to Munishi et al. (2008; 2010), most of the climatic zones show an increase in the probability of dry spells with the probability for a 7-day dry spell showing the strongest change. Generally, except in a few instances, the probability of 7-day, 10-day and 15-day dry spells were higher in the period after the 1970s compared to the period before, which indicates that the probability of dry spells has increased all over the country.

CHAPTER 4 Vulnerability of Woodlands to Climate Change/Variability

Climate change will have wide-ranging effects on the environment and on socio-economic and related sectors, including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity, including woodlands, and coastal zones. As a result of global warming, the type, frequency and intensity of extreme events, such as cyclones (hurricanes and typhoons), floods, droughts and heavy precipitation events, are expected to rise even with relatively small average temperature increases. Changes in some types of extreme events have already been observed, e.g. increases in the frequency and intensity of heat waves and heavy precipitation events (Meehl et al., 2007; UNFCCC, 2007). Such changes in the climate may have a big bearing on the status of the biophysical and socio-economic systems of the region.

CLIMATE VULNERABILITY OF BIOPHYSICAL SYSTEMS

According to UNFCCC (2007), changes in rainfall pattern are likely to lead to water shortages and/or flooding. Temperature increases will potentially severely increase rates of extinction for many habitats and species (up to 30% with a 2°C rise in temperature). The woodlands of Eastern and Southern Africa will be particularly vulnerable to climate change because they occur in areas predicted to be the hardest hit semi-arid areas of the region.

Drought events associated with climate change and climate variability have become more pronounced in the Eastern and Southern African region in recent years, adversely affecting agricultural production. IPCC has reported that all of Africa, including Eastern and Southern Africa, will likely warm during this century, with the drier subtropical regions warming more than the moist tropics. Annual rainfall is likely to decrease throughout most of the region, with more differential patterns in specific locations. The annual rainfall in the Eastern African region is projected to increase causing threats of potential floods and possible damage to resources. On the other hand, areas that will experience decrease in rainfall will likely suffer prolonged droughts with consequences on water and other resources.

Climate Vulnerability and Impacts on Water Resources and Soils

Water-related problems, already serious in the Eastern and Southern African region, are likely to worsen as a result of climate change (AMCEN, 2011). Intense rainfall events will increase the incidence of flooding in many areas. At the same time, reduced run-off will exacerbate water stress and reduce the quality and quantity of water available for domestic, crop and livestock use. Experts predict that Southern Africa will become drier, and that rainfall will increase in parts of Eastern Africa. Drought-prone areas of Botswana and Zimbabwe are likely to become more vulnerable to climate change than more humid areas of Tanzania or Zambia.

According to IPCC (2007) and United Republic of Tanzania (2007, 2009), the water sector, which is crucial for the development of the economy, will be impacted by climate change in different ways. Findings from the IPCC Fourth Assessment Report have alluded that climate change is expected to exacerbate current stresses on water resources from population growth and economic and land-use change, including urbanisation.

In a wider context, the predicted impacts of climate change on water resources in woodlands of Eastern and Southern Africa indicate that by 2020, between 75 and 250 million of people are projected to be exposed to increased water stress. Agricultural production, including access to food, in many Eastern and Southern African countries is projected to be severely compromised due to water scarcity which will further adversely affect food security and exacerbate malnutrition.

The water sector in Eastern and Southern Africa will experience both positive and negative consequences (Munishi et al., 2010). Rainfall pattern and soil moisture will vary due to changes in mean temperature and hence affect the runoff of rivers. For instance, an increase in temperature between 1.8^0C to 3.6^0C in the catchments areas of River Pangani in Northern and North-Eastern Tanzania and a decrease in rainfall has led to a decrease of 6-9% of the annual flow of the Pangani River. The Ruvu River in the Central and Eastern parts of Tanzania and the Sigi River in North-Eastern have experienced a 10% decrease in flow. On the other hand, the Great Ruaha/Kilombero/Rufiji basin would experience an increase in annual rainfall of 5-11%. The impacts of the variability in flow are diverse, including floods in basins that experience increase in runoff and a decrease in flow where annual rainfall decrease, with alteration in availability of water for different uses resulting in water use conflicts among stakeholders. Although flow changes in rivers may be attributed to land use changes in respective catchments, climate change is expected to play major roles, either directly (due to reduced rainfall and increased evapotranspiration resulting from increase in mean temperature) or indirectly through the influence on changes in land use that impacts on the water storage capacity and characteristics of catchments.

It has been observed that several large lakes in sub-Saharan Africa have registered abrupt increases and recessions in surface area and depth, far larger than any witnessed in recent times (Levine et al., 1982; Gillespie et al., 1983; Olago et al., 2007, Opere et al., 2011), suggesting that large areas, today both arid and humid areas, earlier received more substantial rainfall. It has been reported that Lake Malawi has been 50 m shallower than it has been during the last 150 years (Owen-Smith et al., 1990), and records of hydrological change from Lake Naivasha indicates that there were three decadal to inter-decadal scale droughts in the East Africa region that matched oral historical records of famine, political unrest and large-scale migration of indigenous people (Verschuren, 2002). Some regions of Eastern and Southern Africa are particularly vulnerable to reduced precipitation, especially given that the climate trend indicates longer periods of drought and shorter periods of heavy rain. Most vulnerable are the areas of woodlands which are arid, semiarid and dry sub-humid where precipitation is lower than evapotranspiration. There is evidence that droughts are increasing in Southern African dry lands and are expected to increase further as a result of increased temperatures and reduced rainfall.

The catchment of Lake Tanganyika is mostly miombo woodlands of Western Tanzania with the major river Malagarasi originating from the expansive miombo woodlands of Central and Western Tanzania. The water level of the lake has shown a decreasing trend over the past 30 years (Figure 1). The water levels in the Kiwira river in the southern highlands of Tanzania – again in the major miombo eco-region in Tanzania - has been very variable and show a predominant decreasing trend for the past seven years from above 1 620 m to about 1 590 m and the discharge decreased from 6.2 to 5 m^3 sec^{-1} for the period 2000–2011 (Figures 2a & b).

Figure 1. Trends in the Water Level for Lake Tanganyika 1970–2010 (Lake Tanganyika Basin Water Office, 2012).

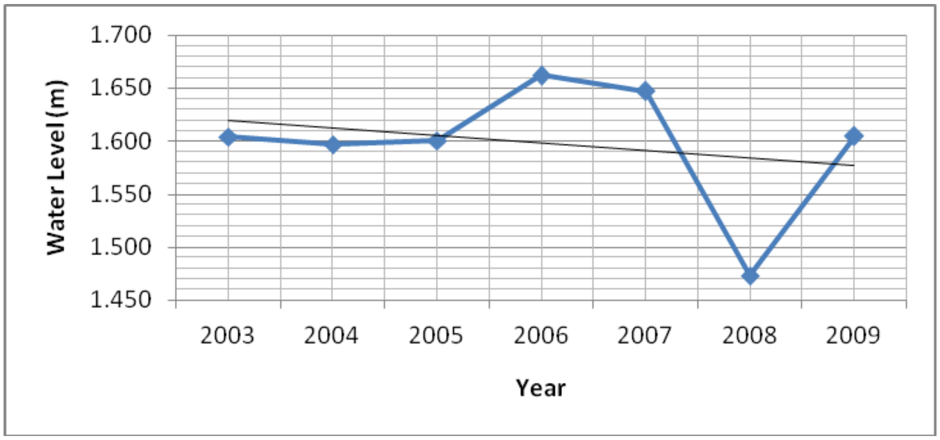

Figure 2a. Water Level Trend in Kiwira River at Natural Bridge 2003–2009.

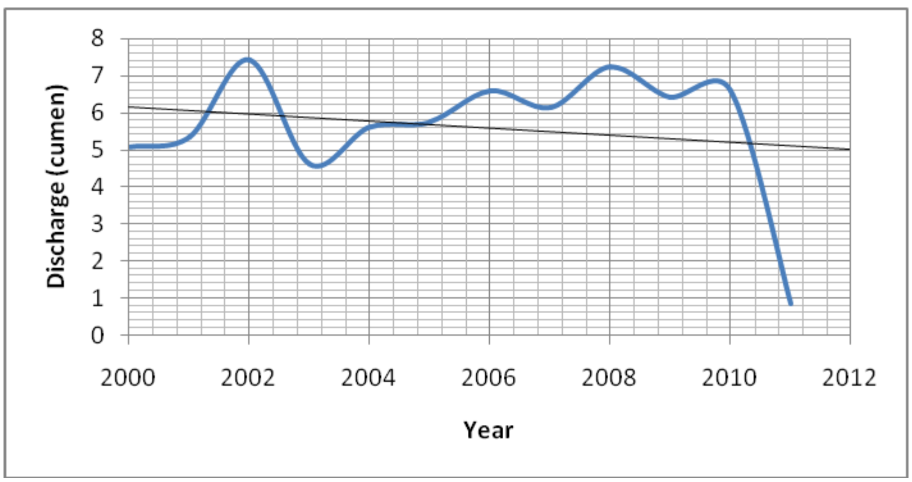

Figure 2b. Discharge Trend in the Kiwira River Southern Highlands of Tanzania 2000-2010.

The major effects of climate change on Eastern and Southern African water systems will be through changes in the hydrological cycle, the balance of temperature, and that rainfall and river flow rates are predicted to decrease (IPCC, 2001; Opere et al., 2011).

Many of the woodlands in Eastern and Southern Africa are situated in vast areas of expansive lowlands and some in highlands like the highland miombo of southern and central Tanzania which are important catchments and sources of water used in the region. Water bodies like Lake Rukwa in Tanzania, Lake Nyasa (Lake Malawi) shared between Malawi and Tanzania, and Lake Tanganyika shared between Tanzania, Zambia and DRC Congo are all surrounded by extensive miombo woodlands and the rivers feeding into these lakes, like Ruhuhu River feeding into Lake Nyasa from Tanzania has its sources/tributaries in the highland miombo of Ruvuma region. Major catchments of the Malagarasi River originate from expansive areas of Miombo woodlands of Central and Western Tanzania, while the Zambezi River passes across expansive areas of Miombo, Mopane, *Terminalia-Combretum*, Zambezi teak (*Baikiaea plurijuga*) and *Acacia* woodlands in Zambia and Zimbabwe. The Pangani River in Northern Tanzania passes through a large area of *Acacia-Commiphora* woodlands in its middle reach with the area contributing substantial discharge into the river.

There are already signs that drought is becoming more common and more prolonged in the drylands of Southern Africa, and drought incidence is expected to increase as a result of higher temperatures and reduced rainfall (IFAD, 2011) negatively influencing flows in streams and water levels in water bodies.

Decreases in water levels or flows in rivers and lakes in the region are attributed to factors related to increasing evaporation due to increased temperature or droughts and decrease in rainfall input from the catchments, or a combination of the two. According to Munishi et al. (2008), the mean annual temperature has increased in all agro-ecological zones of Tanzania while rainfall trends have been variable in different agro-ecological zones with predominantly a decreasing trend. Temperature rises of 0.25–0.5°C per decade have been recorded in Zambia (Chidumayo, 2008), Kenya (Altmann et al., 2002), Kenya and Tanzania (Ogutu et al., 2007) and Uganda (Chapman et al., 2005). However, no clear trend in rainfall patterns has been observed although extreme events, such as droughts and floods, appear to have increased in frequency (Chidumayo, 2011). According to Chidumayo (2011) the significant climate change stimuli, which Eastern and Southern African woodlands are likely to be subjected to in the near future, are most likely related to climate warming due to rising temperatures and extreme events such as droughts and floods. Such trends have, among other things, led to decreased river flows and lowering of lake levels in the Eastern and Southern African region.

Climate change impacts on soils include depletion of soil organic matter resulting from accelerated decomposing due to increase in temperature. Deforestation in the woodlands resulting from socio-economically driven activities, such as agriculture expansion, will and has exposed vast areas of the Eastern and Southern African region to erosion and consequent loss of soil organic matter. Soil carbon makes part of the major carbon pools and is quite vulnerable via deforestation, woodland degradation, and increasing temperature (Munishi and Shear, 2004; Chidumayo, 2011).

Climate Vulnerability of Biological Resources

There is growing evidence that climate change is impacting woodland and forest ecosystems in Eastern and Southern Africa (Kowero, 2011), and therefore the livelihoods of woodland dependent communities as well as national economic activities that depend on woodlands and tree products and services. Africa is one of the most vulnerable regions in the world to climate change. This vulnerability is expected to have considerable negative impacts on the agricultural sector, inevitably increasing the pace of reliance on natural resources, especially natural woodlands and trees. The woodlands of Eastern and Southern Africa also sustain many natural habitats with unique biodiversity, thus contributing to its conservation.

The woodlands of Eastern and Southern Africa fall within several eco-zones, including the miombo woodlands, the *Acacia-Commiphora* woodlands of Tanzania and Kenya (the Somali-Masai Phytochoria), and the Mopane and *Acacia–Combretum* woodlands of Zimbabwe. Such diverse vegetation would imply a variety of habitats and areas of high species diversity and endemism. Climate change impacts on the woodlands in this region will thus likely impact a multitude of biodiversity and vulnerable endemic species.

Because climate is a primary determinant of species distributions and ecosystem processes, changing climates, colder to warmer or wetter to drier or *vice versa*, may promote the formation of new species associations and other ecological changes, but also increase the risk of extinction of species with narrow geographic or climatic distributions and disruption of existing communities. According to IPCC (2007), under climate change woodlands will likely undergo species composition changes and a proportion of species may be threatened or endangered in the future. Loss or alterations of terrestrial habitats by climate change will likely impact animal species found in the woodlands as they struggle to adapt to changing conditions (Lovett et al., 2005). For example, climate change of the magnitude predicted for the 21st century could alter the range of African antelope species (Hulme, 1996) and other herbivores due to changes in food (vegetation) availability. In addition, weather extremes can also affect biodiversity in more complex ways. For example, in African elephants (*Loxodonta africana*), common in most of the woodlands of Eastern and Southern 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).

Differential responses to climate change by species in the woodland ecosystems may lead to disruption of important functional interactions, with potentially serious consequences for the provision of ecosystem services such as pest control, pollination, seed dispersal, decomposition and soil nutrient cycling. Certain ecosystem types will be particularly vulnerable, e.g. ecotones (transition areas between different ecosystems, with high species and genetic diversity), which are important for adapting to climate change while at the same time threatened by it, especially in semi-arid dry lands prone to desertification where most of the woodlands are located.

In Tanzania, assessments of impacts and vulnerability of woodland ecosystems based on the Holdridge life zones predict that sub-tropical dry forest life zones will change to tropical very dry forest and tropical dry forest, subtropical dry forests will decline by 61.4%, and there will be an increase in tropical very dry and dry forests. Further, miombo woodlands on well drained soils would develop into closed woodlands and evergreen forests with increase in precipitation and temperature. Miombo woodlands in areas with poorly drained soil would be replaced by wooded grasslands or thickets/bush-lands in severe cases. Species that will be more vulnerable are those with a limited geographical range and drought/heat intolerant low germination rates, low survival rate of seedlings and limited seed dispersal/migration capabilities.

In Zimbabwe, based on the Holdridge life zones, the vegetation has been divided into five types, i.e. subtropical dry forest, subtropical thorn woodland, tropical very dry forest, subtropical moist forest, and warm temperate moist forest. The Holdridge life zone subtropical dry forest covers the largest area in Zimbabwe (68.7 % by area) and extends across the largest latitudinal range, 15.5"S to 22"S. This zone corresponds to miombo woodland and savannah, Mopane woodland and savannah, *Terminalia-Combretum* woodland, Zambezi teak (*Baikiaea plurijuga*) woodland and *Acacia* woodland according to historic classification systems. In one climate change scenario there is a climate shift towards reduced annual precipitation and higher ambient temperatures. NE Zimbabwe, for example, becomes more suitable for vegetation found under subtropical moist forest conditions in the GISS climate change scenario as opposed to the warm temperate moist forest which exists under current climate conditions. Similarly, the SE region of Zimbabwe is projected to become unsuitable as a subtropical moist forest area and to shift to the subtropical dry forest life zone. The greatest life zone changes are those shifts from subtropical dry forest to tropical very dry forest and from subtropical thorn woodland to tropical very dry forest.

According to Monjane (2009), climate change already has an impact on the dynamics of African biomes, including woodlands and their biodiversity (Erasmus et al., 2002). Degradation of forests due to climate change-induced dieback and land use change could substantially affect species composition and global geochemical cycling, particularly the carbon cycle (Malcolm et al., 2002). Climate change has the potential to alter routes and timings of migrations of species that use both seasonal wetlands and track seasonal changes in vegetation, which may also increase conflicts with humans, particularly in areas where rainfall is low (Thirgood et al., 2004). 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 during the growing season, illustrating that deciduous forests may be more sensitive than grasslands or savannahs to reduced precipitation (Hély et al., 2006). In the savannahs of Zambia, research shows that climate change substantially affects growth of certain tree species. Chidumayo (2004) 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). 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 colonisation.

Plant reproductive processes that might be affected by climate factors include flowering, pollination, seed production and seed germination. The effect of climate change on seed production will depend on flowering phenology, behaviour of pollination agents and fruit/seed development periods. The few observations that have been made in Eastern and Southern Africa suggest that fruiting levels will be negatively affected by climate warming. For example, a negative correlation has been observed between the proportion of fruiting trees in Kibale National Park, Uganda, and minimum temperature (Chapman et al., 2005). Similar observations have been made concerning fruit production in *Strychnos spinosa* in Lusaka, Zambia (Chidumayo, 2011). It appears therefore that climate warming is likely to reduce fruit/seed production in African woodland trees with negative consequences for sexual regeneration and therefore plant genetic diversity. Chidumayo (2008) studied seedling emergence and mortality in relation to climate factors in five savannah woodland trees in central Zambia and assessed their likely responses to a 1°C warmer climate. In four of the species, temperature significantly affected seedling emergence and this was predicted to decline in three of the species but an increase was predicted in one of the species. Temperature also significantly affected seedling mortality in all the five species such that under a warmer climate, mortality was predicted to increase in two of the species but a decrease was predicted in three other species.

Chidumayo (2001) observed that minimum and maximum temperatures had a significant additive effect on woodland leaf phenology (based on the Normalized Difference Vegetation Index [NDVI]), which is a measure of vegetation greenness and therefore productivity. Indeed, recent declines in NDVI in the Mara-Serengeti ecosystem in East Africa have also been attributed to the rise in minimum temperature (Ogutu et al., 2007). A 38 years long series of observations of *Isoberlinia tomentosa* trees in Tanzania revealed significant correlation of tree ring widths and 1) monthly precipitation, 2) monthly maximum air temperature, and 3) monthly Southern Oscillation Index (SOI) value (Trouet et al., 2001). Observations made at a Makeni savannah site in central Zambia also showed that the radial growth of the majority of trees declined due to additive effects of temperature factors which explained a significant proportion of the variation in tree annual growth (Chidumayo, 2011).

However, productivity of the dominant C_4 grasses at the same savannah site increased apparently in response to rising temperatures that was in sharp contrast to the growth pattern in the majority of C_3 trees. This difference in the growth responses of C_3 trees and C_4 grasses may be due to the fact that C_4 photosynthetic pathway is characterised by high water-use efficiency and high optimum temperatures for photosynthesis compared to the C_3 photosynthetic pathway. Most trees in African woodlands are C_3 plants while most grasses are C_4 plants and climate warming is likely to have different effects on these two plant functional groups.

CLIMATE VULNERABILITY OF SOCIO-ECONOMIC SYSTEMS

Eastern and Southern African woodlands are critical for the well-being of people and the provision of a broad range of products, services and functions. They contribute immensely to economic and social development through formal and informal trade in timber and non-timber forest products, to environmental services through their safety net, providing spiritual and aesthetic values, protection of water sources, and by storing considerable amounts of carbon (Monjane, 2009; Munishi et al., 2010). Most of the region's 590 million people live in rural areas where the vast majority interact daily with forests and woodlands, both as nomads and as sedentary farmers, and depends directly or indirectly on the ecosystems for food, fuel wood, building materials medicines, oils, gums, resins and fodder.

It is estimated that woodlands generate at least 20% of the disposable income of landless and poor families, while 85% of the wood removed from woodlands is burned as fuel by both rural and urban residents. The mean woodland area per capita is estimated at 0.62 ha. Wood fuel removal in the region accounted for c. 244 000 million m^3 in 2005 and wood removals for industrial processing at c. 40 000 million m^3 in the same period. Other uses that go unaccounted for include medicinal plants, animal protein (bush meat), protection of water sources and the real value of trade and non-tradable products in the national economies. Production and multi -purpose functions dominate the allocation and use of forest and woodlands in the region, while the protective and social services represent only 11% of the woodland resource base. According to Kowero (2011), forests/woodlands and trees in Africa offer considerable support to agriculture and much of the agricultural belt lies within the dry forest and woodland zones. The forests continue to serve as a reservoir of land onto which agriculture expands. Most agriculture in Africa is rain-fed and therefore very vulnerable to climate variability that is characterised by frequent droughts and occasional floods, which at times destroy crops and livestock. At such times, rural communities increase their reliance on forests and trees for wild food, including fruits, tubers, fish and bush meat, edible insects, beeswax and honey, as well as traditional medicines.

Given the dynamics of climate change impact on woodlands and associated livelihoods, climate change ultimately has the potential to change traditional custodianship of natural resources, frustrate prospect of sustainable natural resource uses, put the livelihoods of people at risk, and to impact availability of water, food security and biodiversity.

Climate Vulnerability of Human Health

Like in any other biomes, human health in the Eastern and Southern African woodland regions will likely suffer from increase in the incidence of diseases. Several health hazards related to climate change have been reported in Tanzania, including malaria which has spread to non-traditional areas, dysentery, cholera, meningitis, typhoid, malnutrition and trachoma. Much of the central regions of Tanzania, where major woodlands are located, already face significant exposure to the above drought related diseases. Even if there is no change in drought frequency or intensity, it is projected that 5% of the population in semi-arid regions will suffer hunger from drought and poor yields and additionally 5% will suffer from trachoma with high cases of dysentery, cholera and almost 200 000 children under five suffering from diarrhoea (Munishi et al., 2010, McKinsey & Company, 2009). It is estimated that about 35.6 million in mainland and 1.1 million people in Zanzibar are at risk. Malaria is endemic across nearly all of mainland Tanzania, with 93% of the population living in areas where *Plasmodium falciparum* (malaria causing parasite) is transmitted. An estimated 100 000 malaria deaths occur annually in Tanzania, of which 80 000 occur in children under five. Approximately 14-18 million clinical malaria cases are reported each year by public health facilities. Nationally, it is estimated that a Tanzanian child under five years of age will have 0.7 cases of malaria per year. It has been estimated that there are approximately 1.7 million cases of malaria in pregnant women and up to 20% of deaths among pregnant women can be attributed to malaria. Also, a significant proportion of anaemia during pregnancy is related to malaria. These cases are likely to increase under the different scenarios of climate change as malaria spreads to non-traditional areas. In Tanzania, for example, malaria has spread widely into areas where it was earlier not present or was scantly present, such as the Northern and Southern highlands. Furthermore, water-related diseases such as schistosomiasis and cholera and other gastrointestinal diseases will likely increase, severe shortage of food and increases in the rate of malnutrition, especially in children, will intensify.

According to the Tanzania National Adaptation Programme of Action (United Republic of Tanzania, 2007) changes in temperature and rainfall regimes have resulted in spread of malaria into non-traditional areas, such as the highlands of Kilimanjaro, Arusha, Iringa, Mbeya and parts of Tanga, among others. Under the current trend in both rainfall and temperature, the frequency of occurrences and impacts of malaria will further rise. The second Vulnerability Assessment Report revealed that among four major health hazards reported at village, district and national levels, malaria is one and the most significant in rural areas. Other major climate change related diseases in Tanzania are dysentery, cholera, and meningitis.

As more areas receive more rains and temperatures increase, resulting from climate change, it will attract more malaria vectors, leading to increased incidences of malaria diseases across the country. Furthermore, the study conducted by Kangalawe et al.(2009) indicates that malaria is endemic in the lowlands but unstable in the highlands of the Lake Victoria region and there is a "creeping-up" of the disease towards the highlands. The study further indicates that women and children are more vulnerable to malaria than men due the roles they play in the society, and that poverty influence adaptation to malaria and/or cholera in the area. According to Munishi et al. (2010), malaria is the largest cause of loss of lives in Tanzania accounting for about 16% of all reported deaths and 19% of national health spending. Figures are probably similar in other Eastern and Southern African countries.

The public health effects of global warming in Eastern and Southern Africa are related to the rising temperatures, severe water shortages and extreme events such as frequent and severe droughts, floods and storms. Climate change has impact on agriculture and food security, water supply, occurrence of extreme natural hazards, mobility and occurrence of infectious diseases, all of which have consequences on health. Higher temperatures, declining rainfall and water scarcity and floods in the Eastern, Central and Southern African region are impacting negatively on food production resulting in food insecurity. Decreased agricultural productivity in the coming years could lead to hunger and famine in some communities severely affected by climate change. This would in turn increase illness and death of vulnerable groups including women and children. Most of the climate change impacts in Eastern and Southern Africa are associated with rainfall variability and scarcity of water resources. Water resources have been decreasing over time as a result of persistent droughts and land use patterns. Climate change will exacerbate water shortages resulting in reduction of hydro-power and increasing the incidence of waterborne diseases and its impacts will be greatest in arid and semiarid areas.

Climate Vulnerability of Livelihoods, Products, Trade and Development

Associated with climate change is an increased incidence of extreme weather events that may lead to local suffering for people and increased environmental impacts (Monjane, 2009). Droughts and floods related to ENSO have already had major human, economic and environmental costs in Eastern and Southern Africa, especially in woodland areas (e.g. the ENSO floods in 1998 in Eastern Africa, in Mozambique in 2000, and in Kenya in 1997/98). As a result of the presence of favourable natural resources, e.g. fertile alluvial soils, water and fisheries, wetlands, lowlands and floodplains are often sites of dense rural and urban settlements. These conditions also prevail in many coastal areas of Eastern and Southern

Africa. Such areas are very prone to socio-economically negative impacts of climate change with consequences on livelihoods.

Many countries show strong links between population, gender equity, the roles and rights of women, and the state of the environment. Changes in the gender balance, e.g. as a result of selective migration due to droughts and water scarcity or disease resulting from climate change impacts, may put additional pressure on women and can aggravate conditions of poverty, with further impact on woodlands and natural resources as a whole. Women's empowerment, beyond the benefit of enhanced decision- making, and their improved access to resources has cumulative effects for improved environmental management and protection, and for community poverty alleviation and security. Security includes predictable access to natural resources and living in a controllable environment that is protected against extreme natural events and human-made disasters (Monjane, 2009). It is undermined when ecosystem services are degraded. For example, a decline in provisioning services due to climate change impacts on woodlands can affect supplies of food, energy and other goods, enhancing the likelihood of conflict over declining resources, and declining regulating services can influence the frequency and magnitude of floods, droughts, landslides and other natural disasters.

Woodlands in South Africa produce benefits for farmers living on customary or communal lands which fall into four categories: i) foods, such as fruit from indigenous woodland trees; ii) other wild foods collected from woodlands, such as mushrooms and edible insects; iii) habitat for small-scale food production, such as honey, and, iv) soil nutrient inputs through nutrient cycling and through nitrogen fixation.

Environmental services, such as protection from soil erosion, are also provided, as well as fodder and browse for goats and cattle, and construction timber, firewood and other material for either domestic consumption or for local sale. Many of these benefits are also available to urban dwellers through the marketplace (Dawees, 1994). Public benefits are of greater relevance to the community, but even so, seldom figure significantly in defining strategies for woodland management. Woodland and tree benefits more generally comprise a range of benefits, including direct, local private benefits, such as foods and fuelwood, which are valued principally for consumptive purposes, or livestock fodder and browse, which are extracted and used for some particular aspect of the farming system rather than for household consumption. It also includes indirect, regional semi-public benefits, resulting from soil retention, stream flow regulation, and recreation, and indirect, global public benefits, from carbon sequestration and the preservation of biodiversity (Bojö, 1992).

It has been observed that potential climate changes and their impact on woodlands are poorly understood at the Eastern and Southern African level. This is because of limited models, computing capacity, facilities, human skills and a unique set of biophysical variables (such as atmospheric dust) (Boko et al., 2007). Notwithstanding these constraints, there is a high level of certainty that the region is extremely vulnerable to climate change where agriculture and food production will be compromised, and water stress will increase (Boko et al., 2007; Bond et al., 2010). Out of the 11 countries in the miombo region, Tanzania, Mozambique, Zimbabwe, southern Zambia, northern Namibia and southern Angola lie in an arc that delineates the area that will experience the highest expected impacts of climate change. Some predictions indicate a 3^{o}C to 7^{o}C increase in temperature by 2080–2099 compared with 1980–1999, while there will be up to 30% less rainfall (Boko *et al.*, 2007). For all the countries in the region this has serious implications. Agriculture is generally the most important economic activity, principally because it is the source of most household income. The predicted scale of the changes will have a devastating impact on agricultural production systems that are already struggling to meet household needs and provide the engine of growth that the region so badly needs. Such changes will also have impacts on the dynamics of livelihoods associated with the use of woodlands, as well as on total livelihoods and the resilience of people to climate-based shocks (Bond *et al.*, 2010).

According to Campbell et al. (2007), Campbell (2009), Campbell et al. (2002), and Bond et al. (2010), for many people in Eastern and Southern Africa, the loss of woodlands and the goods and services that they provide reduces their livelihood options, especially in times of stress. This is particularly important in a region in which the elimination of poverty is proving to be intractable and where climate change is likely to increase the frequency and severity of extreme climatic events (Campbell, 2009). Finally, many of the soils in the miombo region are very fragile and highly susceptible to erosion when the natural vegetation is removed. The loss of top soil from sheet erosion has long-term negative impacts on agricultural production as well as leading to siltation of rivers and dams (Campbell et al., 1988).

CHAPTER 5 Climate Change Mitigation Potential of the Woodlands

The woodlands of Eastern and Southern Africa are important in mitigating and adapting to climate change through its influence on the water cycle, carbon sequestration and storage. Recent estimates of carbon stocks and the effect of agriculture and fire undertaken in the Sofala Province of Mozambique, which has a mean annual rainfall of 690 mm (ranging from 407 mm to 1 219 mm) and is on the dry end of the continuum of vegetation types that constitute miombo woodlands, show no statistical difference between the woodland and cultivated soils in carbon stocks (Williams *et al.*, 2008). These figures do not include the root carbon which has been estimated at 8 $tC.ha^{-1}$ (Ryan, 2009). The analysis of soil and stem carbon in the Nhambita area showed that the estimated stem wood carbon stock was 19.0 (+/- 8) $tC.ha^{-1}$ while estimated median soil carbon stock for undisturbed woodland soils was 57.9 $tC.ha^{-1}$. The estimated median soil carbon on land that had been cultivated was 44.9 $tC.ha^{-1}$, implying a loss of 13 $tC.ha^{-1}$. Stocks of stem wood carbon recovered at 0.7 $tC.ha^{-1}$ per annum on land that had been abandoned for agriculture. There was no discernable increase in soil carbon on lands that had been abandoned for agriculture. The study has some important implications for the management of carbon in the wider miombo woodlands. Firstly, it demonstrates the variability, especially of soil carbon, in dryland forests within a small geographical area. Secondly, the figures provide some broad estimates of the loss of carbon from the conversion of woodlands to agriculture. For example, the loss of soil carbon is about 13 $tC.ha^{-1}$ and stem carbon about 19 $tC.ha^{-1}$ (Williams et al., 2008).

Munishi et al. (2010) estimated the average above ground tree carbon density for Miombo woodland ecosystems in STanzania to be 19.2 $t.ha^{-1}$. The contribution of different tree parts varied, with the overall stem carbon making up c. 40% of the total carbon in the ecosystem while branches contribute the larger proportion of about 60%. Furthermore, different species contribute differently to carbon stocks as influenced by location. *Julbernardia globiflora* store the highest amount of carbon per unit area in Longisonte forest reserve followed by *Brachystegia spiciformis, Uapaca kirkiana, Brachystegia bohemii* and *Parinari excelsa* accounting for 66.5% of the total carbon. The other 13 species accounted for the remaining portion (33.5%). In the Zelezeta site, *B. bohemii* contributed the highest carbon storage followed by *B. spiciformis, P. excelsa, Albizzia antunesiana* and *U. kirkiana*. These species accounted for 98.1% of the total carbon. The four species accounting for the most carbon are common in Miombo woodlands in the South though the most common Miombo species are *B. spiciformis, B. bohemii* and *J. globiflora*. *Uapaca* and *Parinari* sometimes form unique associations in these ecosystems with *Uapaca* forming pure stands on well drained areas thus their high contribution to carbon storage in this Miombo ecosystem. It is concluded from the study that, given their extent, there is apparently a tremendous capacity for the

Miombo ecosystem of Southern Tanzania to store carbon and act as a carbon sink if properly managed. Efforts to ensure proper management of the Miombo ecosystem, putting emphasis on the dominant species, e.g. *B. spiciformis, B. boehmii* and *P. excelsa,* can contribute to the creation of a considerable carbon sink and will ensure persistent potential for the Miombo woodlands as C sinks rather than emission sources thus contributing to the REDD+ process in Tanzania and globally. On the other hand, the Miombo ecosystem is widely utilised by adjacent communities for various purposes, creating high degradation pressure on the ecosystem. In this respect, managing the carbon stocks of these ecosystems require a concerted effort to reduce human related degradation.

CHAPTER 6 Available data and information on Permanent Sample Plots (PSPs) in woodlands and savannahs in Eastern and Southern Africa

AVAILABLE PSP

PSPs in Zambia

The PSPs (Table 1) in Zambia and one in Zimbabwe were established for monitoring the impact of climate change on woodland ecosystems and carbon stocks as well as other parameters of the ecosystem, such as regeneration. Most of the plots seem to have been degraded though some seem to be intact and have potential for future monitoring. On the other hand, even though degraded they would be good sites for monitoring the impacts of deforestation and degradation as well as regeneration and recovery of woodland ecosystems as far as REDD+ is concerned.

Table 2 and Figure 3 present the plots established through the Makeni Savannah Research Project (MASARE). The goal of the project was to contribute to the scientific understanding of plant and plant community responses to environmental change, including climate change, in Zambia.

The Chakwenga Miombo Permanent (CHAMIPE) Plots were established in 1990 and 1991 to study: i) factors affecting the recovery and productivity of miombo woodland after felling, ii) the environmental impacts of miombo woodland clearing, iii) the ecological effects of a traditional burning regime on miombo structure and regeneration, and iv) the impact of climate factors on tree phenology and growth.

According to Chidumayo (2011), of the five sites in the Chakwenga area, the Mwambashi site was cleared and converted to cropland in 2009 by a local resident. The Kankhumba and Kamatupa woodland sites have been subjected to degradation through tree cutting by local people, while both the Chabesha and Nyati Hill regrowth sites were also subjected to selective cutting in the late 1990s and early 2000s but have since then remained relatively undisturbed.

Table 1.Permanent Sample Plots in Different Parts of Zambia and Zimbabwe.

Country	Site	Vegetation type	Status	Latitude S	Longitude E	Area (ha)
Zambia	Mutupa	Miombo	Degraded	12.72	28.43	0.40
	Ndola	Miombo	Converted to urban land use	12.98	28.62	1.20
	Ibenga	Miombo	Intact	13.42	28.22	0.50
	Cheepa	Miombo	Intact	15.00	27.05	1.75
	Makeni	*Piliostigma-Acacia* savannah	Intact	15.47	28.18	1.00
	Mwekera	Miombo	Intact	12.85	28.35	?
	Kankhumba	Miombo	Disturbed	15.22	29.17	0.18
	Chabesha	Miombo	Disturbed	15.25	29.21	0.18
	Mwambashi	Miombo	Converted to cultivation and abandoned	15.28	29.23	0.18
	Kamatupa	Miombo	Disturbed	15.28	29.23	0.18
	Kamatupa Extension	Miombo	Disturbed	15.28	29.23	0.18
	Nyati	Miombo	Disturbed	15.22	29.17	0.18
Zimbabwe	Marondera	Miombo	Intact	18.28	31.46	?

Table 2. Location of the four Chakwenga Miombo Permanent (CHAMIPE) Plots in Chongwe district, East of Lusaka, Central Zambia.

Location	Latitude S	Longitude E	No. of blocks
Kankhumba	15.22	29.17	9
Chambesa	15.25	29.21	9
Mwambashi	15.28	29.23	9
Kamatupa	15.28	29.23	9
Kamatupa Extension	15.28	29.23	10
Kankhumba Extension	15.22	29.17	9
Nyati hill	15.24	29.22	6
Note: The GPS positions refer to the centre of the plot. Source: Chidumayo, 2011.			

BIOTA Southern Africa Biodiversity Observatories Vegetation Database

The BIOTA Southern Africa Biodiversity Observatories Vegetation Database (AF-00-003) (Muche et al., 2012) hosts the project-related data on spatial patterns and time series of biodiversity in Southern Africa. Along a 2000 km long transect, from the northern border of Namibia to the Cape of Good Hope, the plant diversity has been monitored on 37 Biodiversity Observatories for up to ten years (2001–2010). The design of the Observatories enables the observation of vegetation in nested, permanent plots where standardised measurements can be repeated. Information on species occurrence, cover and abundance has been recorded annually and stored in a database.

Figure 3. BIOTA Biodiversity Observatories of Southern African biomes (Muche et al., 2012).

Each BIOTA Biodiversity Observatory encompasses an area of 1 km² (1,000 m × 1,000 m) with the boundaries oriented along cardinal directions. This 1 km² area is divided into 100 1 ha plots (100 m × 100 m). All corner points are georeferenced and visually marked with metal poles. The hectare plots represent the largest replicated sampling unit within the BIOTA Observatory (Jürgens et al., 2010a, 2011). The plots are classified according to habitat types and subjected to a habitat-stratified ranking (for further details on the ranking procedure, see Jürgens et al. (2010b). North of the centre of the hectare plot, a 10 m × 10 m plot is laid out and nested inside a 20 m × 50 m plot (Figure 4). The 100-m² and 1000-m² plots within the 20 highest ranked hectare plots are monitored annually during the peak of the growing season. On the 100 m² plots, all vascular plant species are recorded for their abundance and the projected cover values in percentages (down to 0.01%). On the 1 000 m² plots, vascular plant species are recorded for their projected cover values and on the hectare plot (10,000 m²) only for occurrence.

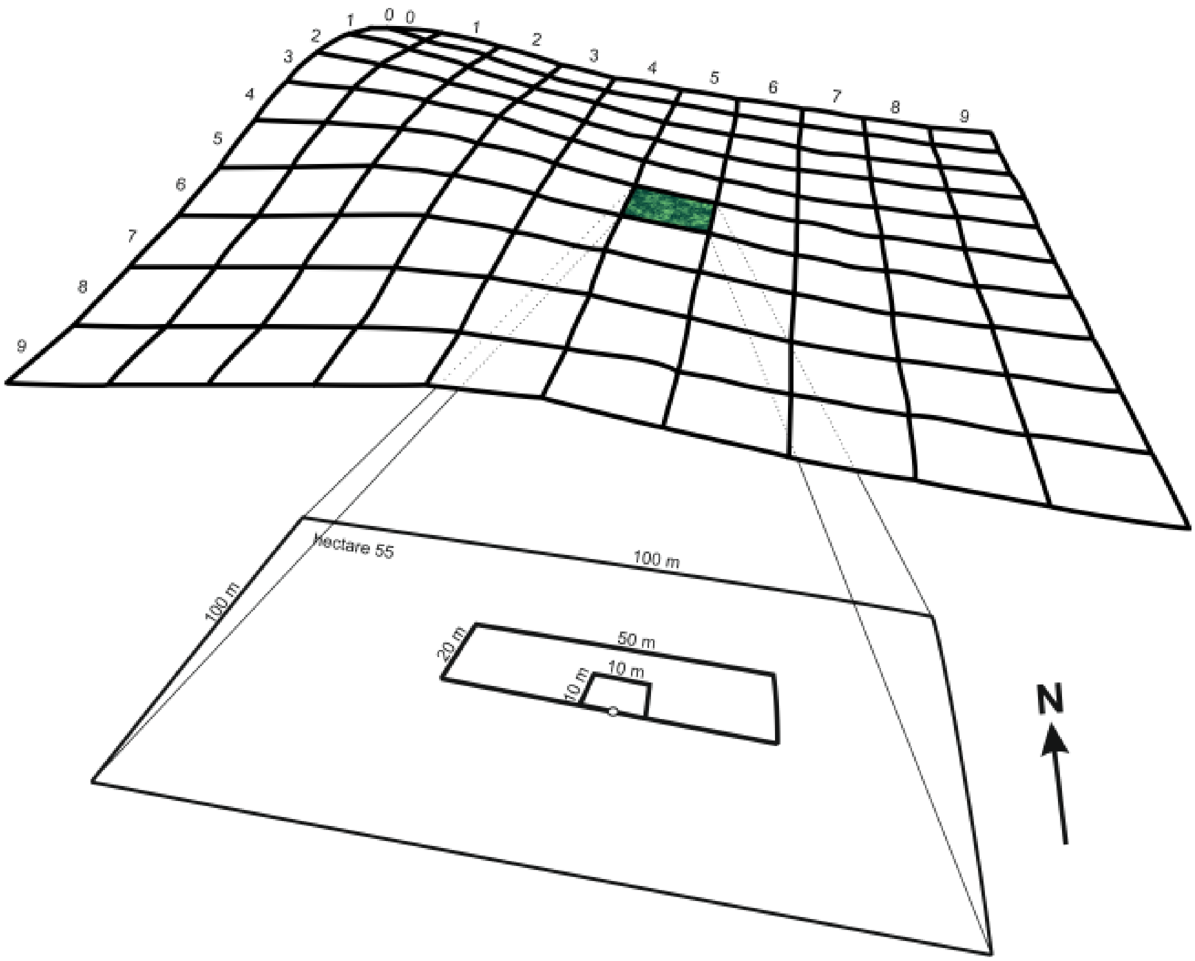

Figure 4.Design of the BIOTA Biodiversity Observatories (Muche et al., 2012).

PSPs in Tanzania

ThePSPs in the woodlands of Tanzania are of three different sizes:

i) 1 ha permanent plots measuring 100m x 100m subdivided into 25 subplots of size 20m x 20m;

ii) 0.08 ha plots measuring 20m x 40m subdivided into 8 sub-plots measuring 10m x 10m; and,

iii) 0.07 ha concentric circular plots (15m radius) subdivided into 3 nested concentric rings of 5, 10 and 15m radius for assessments of different tree sizes and growth forms.

These plots have been established by different programmes. The 1ha plots were established by the “Valuing the Arc” Project, and a REDD pilot project on ‘Enhancing

Tanzanian Capacity to Deliver Short and Long Term Data on Forest Carbon Stocks across the Country'. The 0.08 ha plots were established by the CCIAM project on 'Quantification and Mapping Carbon Stocks in Different Land Use Types in Tanzania' and a REDD pilot project on Piloting REDD in the Pugu-Kazimzumbwi Forest Reserves, while the 0.07ha plots were established by the National Forest Resource Assessment Program (NAFORMA).

Except for in the NAFORMA plots, where only biomass and soil carbon are assessed, in all the other plots the five carbon pools are assessed based on IPCC requirements. These pools include:

- biomass carbon (above and below ground);
- soil carbon, normally measured at different depths and averaged for the site;
- litter carbon;
- undergrowth carbon; and
- dead wood carbon.

All trees with DBH≥ 10 cm are measured for DBH. The measured trees are permanently marked to enable future monitoring of changes in carbon. Each tree is therefore marked at the measurement point and tagged using numbered aluminium tags, and the plots are geo-referenced at each corner, i.e. the Easting and Northing are recorded for each plot or each corner of the plot. The PSPs in Tanzania are described in Tables 4, 5, 6. Other plots exist which were established for forest inventory by NAFOMA.

There are more than 30,000 circular concentric plots country wide of 15m radius (0.07 ha) some of which are used as permanent forest monitoring plots, including for carbon monitoring. When assessing carbon only the above ground biomass and, to some extent, soil carbon is measured. The coordinates of the plot location can be obtained from the Forestry and Beekeeping Division of the Ministry of Natural Resources and Tourism (Figure 5). Furthermore, there are past PSPs for forest inventory and monitoring that were established by TAFORI but the location and status of these plots are not clear.

Table 3. Description of the BIOTA Data (Muche et al., 2012)

<table>
<tr><td colspan="2">GIVD Database ID: AF-00-003</td><td colspan="2">Last update: 2012-05-30</td></tr>
<tr><td colspan="4">BIOTA Southern Africa Biodiversity Observatories Vegetation Database</td></tr>
<tr><td colspan="4">Scope: Vegetation and environmental data in Namibia and western South Africa within the BIOTA Biodiversity Observatories</td></tr>
<tr><td colspan="2">Status: ongoing capture</td><td colspan="2">Period: 2001-2010</td></tr>
<tr><td colspan="4">Database manager(s): Gerhard Muche (gerhard.muche@uni-hamburg.de)</td></tr>
<tr><td colspan="4">Owner: BIOTA Data Facility</td></tr>
<tr><td colspan="4">Web address: http://www.biota-africa.org</td></tr>
<tr><td>Availability: according to a specific agreement</td><td colspan="2">Online upload: no</td><td>Online search: no</td></tr>
<tr><td colspan="2">Database format(s): MS Access, BIOTABase</td><td colspan="2">Export format(s): MS Access, CSV file, Cornell condenses format, Canoco environment data</td></tr>
<tr><td colspan="2">Plot type(s): normal plots; nested plots; time series</td><td colspan="2">Plot-size range: 0.01-10 000 m²</td></tr>
<tr><td>Non-overlapping plots: 4 083</td><td colspan="2">Estimate of existing plots: 4 083</td><td>Completeness: 100%</td></tr>
<tr><td>Total plot observations: 12 808</td><td colspan="2">Number of sources: 1</td><td>Valid taxa: 2 468</td></tr>
<tr><td colspan="4">Countries: NA: 62.7%; ZA: 37.3%</td></tr>
<tr><td colspan="4">Forest: 3% — Non-forest: aquatic: 0%; semi-aquatic: 0%; arctic-alpine: 0%; natural: 69%; semi-natural: 29%; anthropogenic: 0%</td></tr>
<tr><td colspan="4">Guilds: all vascular plants: 100%</td></tr>
<tr><td colspan="4">Environmental data: altitude: 56%; slope aspect: 28%; slope inclination: 34%</td></tr>
<tr><td colspan="4">Performance measure(s): presence/absence only: 25%; cover: 75%</td></tr>
<tr><td colspan="4">Geographic localisation: GPS coordinates (precision 25 m or less): 100%; political units or only on a coarser scale (>10 km): 100%</td></tr>
<tr><td colspan="4">Sampling periods: 2000-2009: 99.0%; 2010-2019: 1.0%</td></tr>
<tr><td colspan="4">Information as of 2012-07-12; further details and future updates available from http://www.givd.info/ID/AF-00-003</td></tr>
</table>

Table 4.PSPs in Different Locations in Iringa and Mbeya Miombo Woodlands.

Region	Plot No.	Location	Coordinates				Elevation (m)
			SE Corner	NE Corner	SW Corner	NW Corner	
Iringa	1	Kidunda Kiyave VFR	780291, 9158721	780294, 9158820	780195, 9158716	780189, 9158818	1200
	2	Kidunda Kiyave VFR	779626, 9160576	779623, 9160672	779524, 9160572	779525, 9160673	1090
	3	Kidunda Kiyave VFR	782622, 9159246	782623, 9159340	782519, 9159234	782520, 9159334	1226
	4	Gangalamtumba VFR	785429, 9162583	785424, 9162685	785331, 9162587	785329, 9162685	1256
	5	Gangalamtumba VFR	784306, 9160732	784302, 9160829	784210, 9160732	784215, 9160834	1248
	6	Gangalamtumba VFR	782796, 9162133	782796, 9162226	782702, 9162134	782709, 9162228	1099
	7	Gangalamtumba VFR	785666, 9164910	785671, 9165014	785568, 9164910	785565, 9165006	1115
	8	Kitapilimwa FR	792968, 9163460	793628, 9161798	792865, 9163459	792861, 9163564	1353
	9	Kitapilimwa FR	793627, 9161696	793628, 9161798	793527, 9161707	793532, 9161802	1364
	10	Nyanyembe VFR	707870, 9049102	707875, 9049194	707775, 9049107	707779, 9049205	1607
	11	Mlimba VFR	702273, 9049667	702280, 9049761	702176, 9049672	702181, 9049770	1429
	12	Mtuya PF	725516, 9070976	725513, 9071075	725419, 9070964	725413, 9071065	1861
	13	Bumilayinga PLF	728465, 9072236	728461, 9072335	728368, 9072242	728357, 9072340	1932
	14	Igula VFR	721540, 9091742	721540, 9091841	721441, 9091735	721436, 9091834	1564
	15	Ikelele VFR	722899, 9094698	722894, 9094798	722801, 9094701	722794, 9094802	1731
	16	Mandumburu FR	729010, 9087586	729002, 9087684	728909, 9087584	728910, 9087685	1660
	17	Nyangwila GL	720413, 9094435	720409, 9094534	720317, 9094417	720307, 9094521	1631
	18	Makiri GL	719576, 9100737	719570, 9100835	719478, 9100737	719470, 9100835	1506
	19	Makiri GL	718007, 9103436	718005, 9103535	717903, 9103432	717902, 9103534	1400
	20	Chauling'ina VFR	727416, 9094929	727421, 9095026	727319, 9094936	727321, 9095032	1705
Mbeya	21	Manga VFR	548683 9085201	548790 9085205	548686 9085306	548788 9085305	1345

	22	Mapogoro PLF	549717 9090064	549722 9090158	549620 9090063	549617 9090158	1361
	23	Patamela VFR	505571 9074331	505581 9074431	505469 9074335	505474 9074430	1109
	24	Ilunga VFR	504700 9076814	504695 9076917	504601 9076795	504595 9076901	1142
	25	Mbangala PLF	478155 9087711	478151 9087807	478055 9087708	478055 9087807	1086
	26	Kapalala PLF	476590 9092935	476586 9093036	476490 9092932	476486 9093035	1131
	27	Kapalala PLF	473120 9097487	473132 9097590	473031 9097493	473029 9097595	1140
	28	Kapalala PLF	472203 9102491	472308 9102496	472203 9102593	472307 9102598	1031
	29	Kapalala PLF	469226 9105345	469329 9105348	469230 9105447	469331 9105451	1040
	30	Kapalala PLF	459601 9112882	459601 9112986	459499 9112888	459506 9112988	1030
	31	Guwa PLF	454927 9120651	454934 9120748	454833 9120655	454832 9120756	1086
	32	Guwa PLF	450765 9122286	450772 9122385	450662 9122294	450666 9122393	1149
	33	Kapalala PLF	472373 9114347	472372 9114452	472275 9114347	472276 9114449	1132
	34	Godima PLF	557175 9058783	557168 9058885	557076 9058780	557069 9058884	1574
	35	Itagano PLF	531175 9023630	531171 9023730	531079 9023623	531171 9023730	1769
	36	Senjele FR	516803 9008342	516800 9008437	516705 9008339	516698 9008435	1599
	37	Ivuna FR	454103 9035919	454084 9036015	454001 9035918	453993 9036017	1280
	38	Ivuna FR	448170 9041475	448164 9041580	448066 9041484	448071 9041590	1101
	39	Ivuna FR	448071 9041590	442403 9048394	442305 9048298	442304 9048394	1088
	40	Ivuna FR	440206 9053678	440195 9053772	440102 9053677	440098 9053776	1153

Source: Pilot Project on Enhancing Tanzanian Capacity to Deliver Short and Long Term Data on Forest Carbon Stocks across the Country – SUA/WWF.

Notes: Plot size: 1 ha; Establishment year: 2010.

Table 5.PSPs in Hanang Northern Tanzania.

Plots	Eastings	Northings	Elevation (m)	Location	Vegetation type
1	771638	947980	1662	Hanang FR, Hanang District	Miombo woodland
2	771770	9480372	1666		
3	771398	9479352	1640		
4	771924	9480765	1668		
5	771304	9478930	1640		
6	771764	9481199	1643		
7	771002	9478584	1626		
8	771766	9481656	1636		
9	771054	9478174	1634		
10	771851	9482092	1629		
11	770977	9431444	1623		
12	772048	9482437	1618		
13	770566	9481360	1626		
14	771154	9481860	1617		
15	770134	9481166	1634		
16	771384	9482234	1621		
17	770419	9480820	1639		
18	771595	9482637	1609		
19	770517	9480054	1642		
20	771946	9479507	1650		
21	770918	9480316	1654		
22	772333	9479333	1614		
23	771690	9479086	1638		
24	772895	9479350	1590		
25	770832	947922	1610		
26	773133	9479720	1602		
27	770402	9478914	1611		
28	773018	9480213	1641		
29	770157	9478524	1603		
30	772822	9480574	1652		
31	770182	9478080	1583		
32	772810	9480980	1648		
33	772135	947894	1651		
34	772913	9481428	1631		
35	771797	9478250	1636		

36	772927	9481830	1624		
37	771341	9478254	1632		
38	772504	9481840	1634		
39	771340	9477824	1614		
40	772550	9482284	1622		

Source: CCIAM Project on Quantification and Mapping Carbon Stocks in Different Land Use Types in Tanzania.

Notes: Plot size: 0.08 ha; Establishment year: 2012.

Table 6. PSPs in *Acacia-Commiphora* Woodlands in Same District, Tanzania

Plot No	Location	Coordinates					Elevation (m)
		SE Corner	NE Corner	SW Corner	NW Corner	Centre	
1	Emuguri	342790 9559019	342784 9559058	342764 9559018	342765 9559056	342773 9559036	835
2	Emuguri	341250 9557823	341248 9557862	341228 9557823	341229 9557862	341240 9557843	796
3	Lesirwai	334865 9553770	334902 9553772	334862 9553791	334902 9553791	334883 9553782	649
3	Lesirwai	334865 9553770	334902 9553772	334862 9553791	334902 9553791	334883 9553782	649
4	Njaktai	335353 9551350	335345 9551384	335330 9551342	335319 9551383	335338 9551363	649
5	Marwa	336283 9549748	336275 9549788	336261 9549749	336262 9549790	336274 9549766	644
6	Marwa	338953 9545774	338953 9545795	338915 9545775	338916 9545795	338934 9545784	657
7	Mferejini	337333 9531175	337334 9531218	337317 9531191	337314 9531215	337325 9531203	644
8	Mferejini	337277 9532646	337273 9532687	337256 9532648	337253 9532689	337268 9532668	646
9	Lesirwai	331543 9557728	331548 9557766	331523 9557729	331527 9557767	331535 9557746	657
10	Emuguri	343497 9555743	343494 9555784	343475 9555743	343479 9555781	343485 9555763	809
11	Emuguri	345525 9558540	345529 9558580	345506 9558537	345507 9558577	345517 9558558	891
12	Emuguri	347205 9554543	347202 9554502	347184 9554544	347182 9554504	347192 9554523	855

Source: CCIAM Project on Quantification and Mapping Carbon Stocks in Different Land Use Types in Tanzania.
Notes: Plot size: 0.08 ha; Establishment year: 2012.

CURRENT STATUS AND POTENTIAL OF THE PLOTS FOR THE GENERATION OF DATA AND INFORMATION

Most of the plots in Zambia seem to have been degraded while some remain intact or relatively undisturbed. On the one hand, those plots that have been converted to other land uses, such as urban or cultivated land, cannot be used for future monitoring. On the other hand, those that remain intact or only lightly disturbed can be good sites for monitoring human and naturally induced disturbances on the ecosystem. This is very much so with regards to effects of deforestation and degradation, and hence REDD+. Given the fact that the baseline information of such plots exists, they can be used for generation of data and information for future monitoring of the dynamics and functions of this ecosystem and for REDD+. However, some modifications may be undertaken to make them more suitable for monitoring for REDD+, especially with regard to acquiring more data related to monitoring carbon pools.

The plots in South Africa were established for monitoring biodiversity but carbon was not assessed and they would require additional protocols for assessing carbon stocks in order to be suitable for monitoring the impacts of climate change on the ecosystems and monitoring for REDD+. All in all, these plots are suitable as starting points for monitoring impacts.

The plots in Tanzania were mainly established for the purpose of monitoring carbon. However, the other ecosystem parameters, such as regeneration, were sparingly covered and may only be inferred, as they seem not to have been assessed adequately. In this respect, additional information may be required in order to monitor other parameters.

Generally, all available plots are suitable for monitoring future changes in the ecosystems as well as monitoring for REDD+. Monitoring and establishing changes in carbon stocks over time is an important process in REDD+ that would show additional benefits of a carbon project.

INSTITUTIONAL ARRANGEMENTS FOR THE SUSTAINABLE MANAGEMENT AND MONITORING OF THE PLOTS

The PSPs described in this report were established by the various institutions either for the purpose of monitoring forest growth in the case of the inventory plots, or to serve as baseline for MRV in case of REDD+ and biodiversity/ecological monitoring initiatives. Given this fact, the following approaches are proposed:

1) The institutions that established the plots would be the best suited to continue monitoring them in order to ensure consistency of information collected and for justifying future predictions and modelling of changes. Further, there has not been a single approach to assessment of the plots and each approach, and reason for its use, is known better by the institution that established the plots. Using the same institutions would make the assessment more efficient given the knowledge and determination embedded in these institutions. They may have intended to continue monitoring the plots but got limited by lack of funding. The REDD+ initiatives might be an opportunity to resume monitoring of these plots.

2) In the case where the institutions that established the PSPs are academic/training institutions, there is an added advantage in the substantial, determined and scientific labour force of students who can undertake research in various natural resources fields. In this respect, student research would be led towards re-assessment of the plots under very close supervision to ensure generation of consistent data of high quality. This is expected to generate a large volume of information quickly and more efficiently. Given the need for improved knowledge on forest monitoring and MRV in the case of REDD+, using the student research approach would be a good avenue for capacity building in generating long-term data on forests and carbon.

3) In cases where the two approaches above are not feasible, Forestry Research Institutions in the countries could be given the task of monitoring the PSPs. This would, however, require capacity enhancement and training on the different approaches that have been used by the different institutions that established the plots.

4) As a more general approach, the work could initially be done by the institutions that established the plots while building the capacity of Forestry Research Institutions in the different approaches for monitoring forest growth and MRV, then let the research institutions take the lead and work in collaboration with especially academic, training and research institutions in respective countries. This may be a longer process but important in ensuring consistency of the data that is collected.

CHAPTER 7 Conclusions

The woodlands of Eastern and Southern Africa are of various types, including Miombo Woodlands covering about one-third of the region, *Terminalia-Combretum* woodland savannahs, Mopane and Zambezi Teak (*Baikiaea plurijuga*) woodlands. Further, *Acacia-Combretum* woodlands in Zimbabwe and *Acacia–Commiphora* woodlands in Kenya and Tanzania also form major woodland types.

There is substantial evidence that climate change is affecting rainfall patterns, water availability, sea levels, and the dynamics of droughts and bushfire frequency, all of which are increasingly impacting on woodland ecosystems, associated livelihoods, human health, agriculture productivity and biodiversity.

Climate change will have wide-ranging effects on the environment and on socio-economic and related sectors, including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity, and the woodlands of Eastern and Southern Africa will be responding to variable rainfall in terms of seasonality and amounts with predominantly decreasing rainfall and increasing temperatures.

The public health effects of global warming in Eastern and Southern Africa are related to rising temperatures, severe water shortages and extreme events. Climate change will therefore impact on agriculture and food security through water supply, occurrence of extreme natural hazards, and mobility and occurrence of infectious diseases, all of which will also have consequences for health.

The predicted scale of changes in climate may have serious negative impacts on agricultural production systems and on the dynamics of livelihoods associated with the use of the woodlands of Eastern and Southern Africa. Total livelihoods and the resilience of people to climate-based shocks will be affected. For many people in Eastern and Southern Africa, the loss of woodlands and the goods and services that they provide, will reduce their livelihood options, especially in times of stress.

Most PSPs in Zambia seem to have been degraded while some remain intact or relatively undisturbed. Given the fact that the baseline information of such plots exists, they can still be used for generation of data and information for future monitoring of ecosystem dynamics and REDD+. However, some modifications may be needed to make them more suitable as monitoring sites for REDD+, especially with regard to acquiring more data on carbon pools that need to be monitored according to IPCC requirements.

The plots in South Africa were established for monitoring biodiversity and not for carbon and would require additional protocols for assessing carbon stocks.

The plots in Tanzania were mainly established for the purpose of monitoring carbon. However, other ecosystem parameters, such as regeneration, were sparingly considered and they may only be inferred, as they do not seem to have been assessed adequately. In this respect, additional information may be required in order to monitor such other parameters.

Generally, all available plots are suitable for monitoring future changes in the ecosystems as well as for REDD+. Monitoring and establishing changes in carbon stocks over time is an important process in REDD+ that would result in additional benefits from carbon projects.

On the issue of intuitional arrangements for the sustainable management and monitoring of the plots, four options are suggested:

1) The work be done by the institutions that established the plots in the first place as they would be the best suited to continue monitoring the plots in order to ensure consistency of the information collected;

2) Use academic, training and research institutions in forestry where there is a substantial, determined and scientific labour force of students who can undertake research in fields related to the PSPs; thus, this is a good avenue for capacity building in generating long term data on forests, carbon and MRV;

3) Where the two approaches are not feasible, Forestry Research Institutions in the countries could be given the task though this would require capacity enhancement/training on the different approaches that have been used by the different institutions to ensure consistency in data;

4) A more general approach where initially the work would be done by the institutions that established the plots, while building the capacity of Forestry Research Institutions in the different approaches for monitoring forest growth and MRV, then let the research institutions take the lead and, preferably, work in collaboration with academic, training and research institutions.

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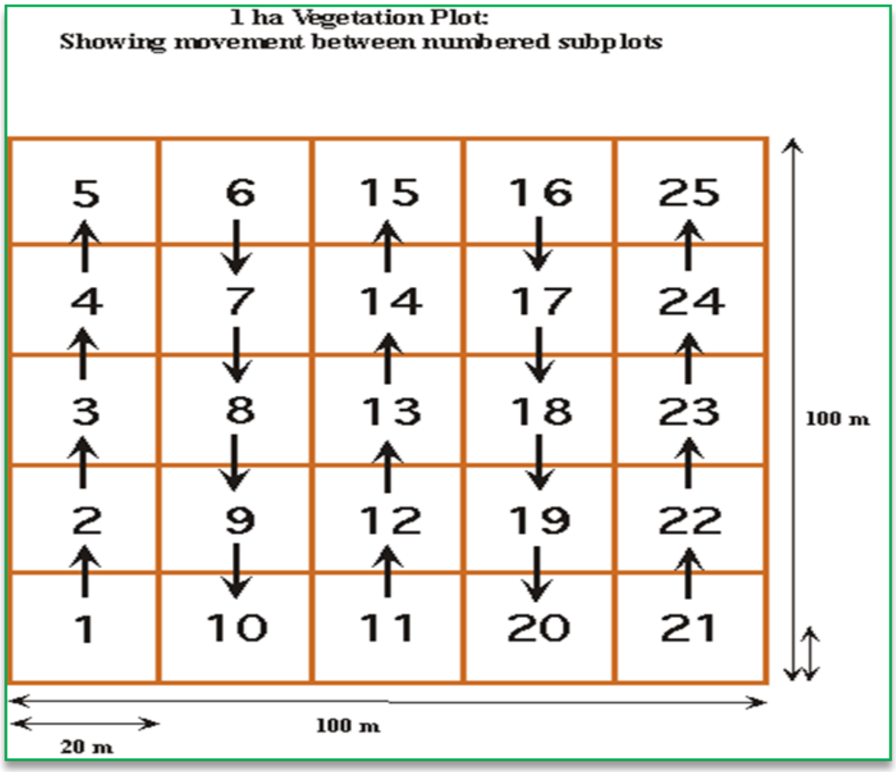
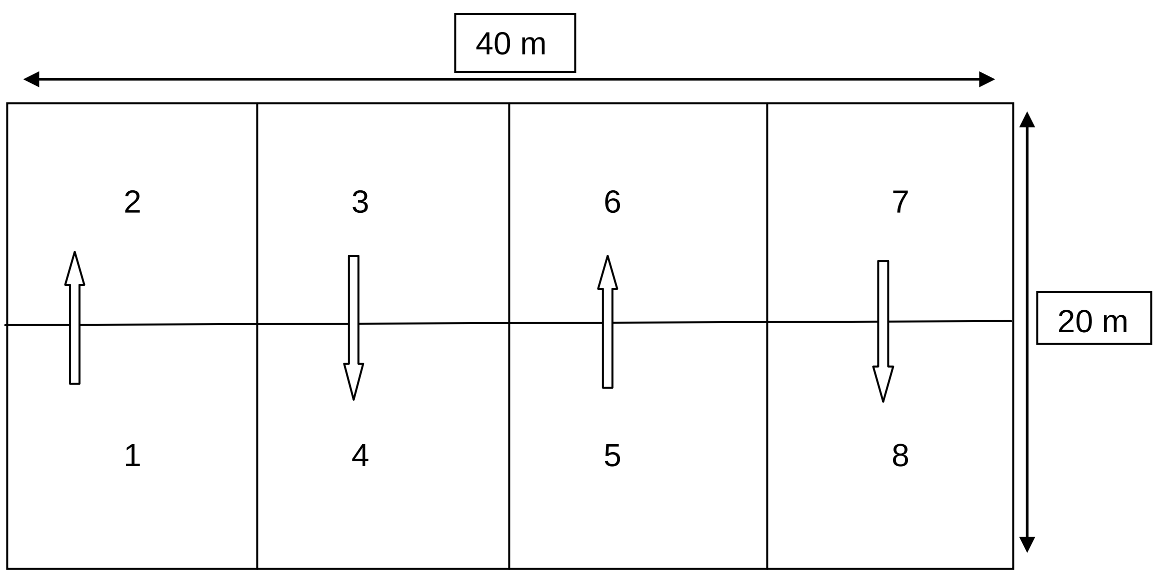
Appendix 1

The 1 ha Carbon Monitoring Plots Used in Tanzania (adopted from TEAM, VtA).



Appendix 2

The 0.08 ha Plot Approach Used in Tanzania (Adopted from Munishi et al., 2010).



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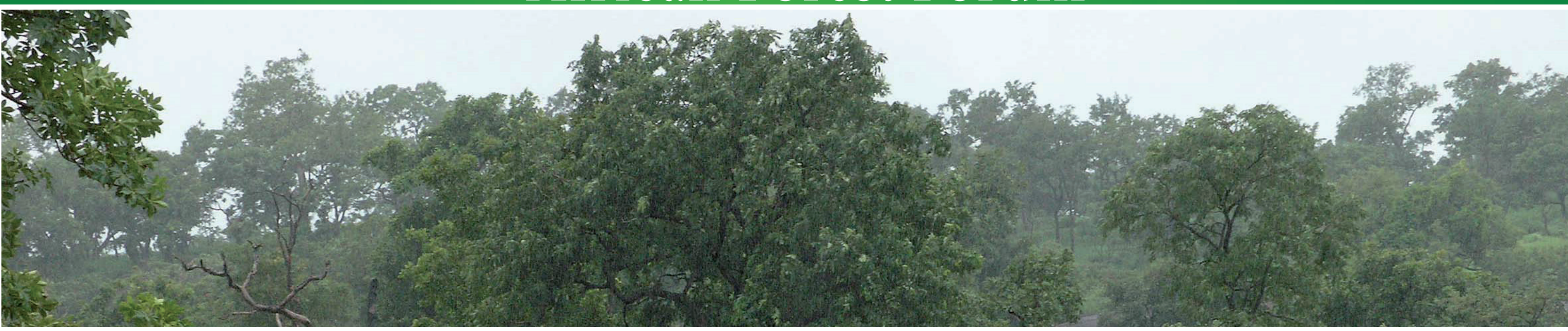

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