Aspects of climate change and its associated impacts on wetland ecosystem functions - A review

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Abstract: Wetlands are one of the richest ecosystems on the earth and have enormous environmental and socioeconomic benefits to humanity. Scientific evidence is growing on the occurrence of human-induced climate change. Wetlands are among the ecosystems most vulnerable to anthropogenic activities being aggravated by climate change. This change in climate has the potential to alter water temperature, flow, runoff rate and timing, and the physical characteristics of the wetlands. Such disturbances vary in strength, frequency, predictability, duration, and spatial scale, and can disrupt ecological processes. These changes will have effects on the functioning of wetlands and then lead to changes in the critical goods and services of wetlands upon which human societies depend on. Wetlands are rich with many species of amphibians, small mammals, fishes, birds and aquatic plants. The value of wetlands as a habitat for these species depends on the size of the wetlands, diversity of vegetation, water quality, and soil conditions. However, these factors are under the major threats of climate change. The most pronounced effects on wetlands will be altered hydrological regimes and more frequent or intense extreme weather events. Wetlands in the tropics rely on direct precipitation and are most likely to be affected by climate change. A future hotter and drier climate may reduce wetlands in size, and convert some wetlands to dry land leading to a significant loss and degradation of the resources and associated biodiversity. The present paper reviews the current state of knowledge of the impacts of climate change on wetlands. It also assesses the types, and functions of wetlands which are more vulnerable to the impacts of climate change. The paper also suggests as a conclusion the importance of integrating strategies that help wetland ecosystems accommodate changes adaptively and mitigation actions that reduce anthropogenic influences on climate into the overall wetland management plans.

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1. Introduction

Wetlands, as the term might suggest, are the collective terms for ecosystems whose formation, processes and characteristics have been dominated and controlled by water. However, wetlands lack widely accepted definition; hence, institutions and individuals in different countries have given different definitions. In this regard, Philipose and Thomas (2003) defined wetlands as areas where water is the primary factor controlling the environment and associated plant and animal life. Whereas Bardeckil (1991) and Mitsch and Gosselink (2002) described wetlands as being ecotones, i.e., transitional environments between terrestrial areas such as forests and farmlands and aquatic ecosystems such as rivers, lakes, etc. combining the structural and functional attributes. Concerning their occurrence, Niering (1997) stated that wetlands occur where the water table is at or near the surface of the land, or where the land is covered by shallow water. Nowadays, in general, the world have agreed to define wetlands as areas of marsh, fen, peatland or water, whether natural or artificial, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters (Ramsar Convention, 1971).

The extent of the world's wetlands is generally thought to range from 7 to 9 million km^2 (about 4 to 6% of the land surface of the earth) (Mitsch and Gosselink, 2002), and the minimum global estimate is considered to be 7.8 million km^2 (US EPA, 2004). But, according to Reddy and DeLaune (2008), approximately 6% of Earth's land surface, which equals about 2 billion acres (approximately 800 million hectare), is covered by wetlands. However, their area coverage in Africa has not yet been known exactly. As a result, different estimates have been given regarding the total wetland area. For example, Hillman (1993) estimated that the wetlands in Ethiopia have the total area of 13,699 km2 (1.4%) of the country's land surface whereas EPA (2003) stated that wetland is estimated to cover 18,587 km2 (1.5%) of the total land area of Ethiopia.

Wetlands are very important as they have great economic, cultural, scientific and recreational values. Various studies have indicated that wetlands are the richest ecosystems next to tropical rainforests found on this planet earth, supporting high levels of biological diversity and providing essential life support for much of humanity. Hence, they have been called 'biological supermarkets' because of the extensive food chain and rich biodiversity that they support. They are sometimes described as 'the kidneys of the landscape' because they function as the downstream receivers of water and waste from both natural and human sources, and thus ameliorating floods, cleanse polluted waters, recharge groundwater aquifers, etc. (Philipose and Thomas, 2003). They offer habitats to a wide variety of plants, invertebrates, fishes, amphibians, reptiles and mammals, as well as to millions of both migratory and sedentary water birds.

Indeed, they are the only ecosystem types specifically identified for conservation by international convention, i.e., the Ramsar Convention of 1971 (Bardeckil, 1991). However, in different parts of the world, wetlands are still under threat from various anthropogenic activities such as agriculture, urban expansion, etc. This problem is especially common in Africa. According to Bognetteau (2003), successive drainage of wetlands for food production has been undertaken for decades in some part of Africa. In general, draining for dry season food crops cultivation, the appearance of invasive plant species due to mismanagement of the resources, over-extraction of resources beyond their restoring capacity, the introduction of perennial crops into the wetland ecosystem, etc. are still some of the major threats that are affecting wetlands in Africa. As a result of these and other related reasons, most wetlands are being severely degraded at an alarming rate in many parts of Africa and most the fauna and flora species are getting endangered. As part of the global systems, the wetlands in Africa could not also escape from the negative impacts of the global climatic changes. Recent studies indicate that climate change will undoubtedly have an effect on wetland ecosystems. Thus, taking this global issue into consideration overview of why wetland ecosystems are important and what the impacts of climate change are on these ecosystems and their associated species are reviewed.

2. Types of Wetlands

Wetlands differ due to various factors such as hydrology (water regime), water chemistry, existing plant and animal life, etc. Verry (1997) stated that the source of water determines the wetland types. According to Bardeckil (1991), wetlands include a wide variety of ecosystem types including tidal salt marshes, freshwater marshes, forested swamps, mangrove swamps, fens, bogs, tropical reed swamps, seasonally flooded riparian forests, etc. In general, according to Cowardin *et al.*(1979), there are five recognized major wetland system types as marine, estuarine, lacustrine, riverine, and palustrine. Of the global total wetland area estimated, the greatest part is occupied by wetlands in freshwater environments (Table 1).

Marine and estuarine systems describe coastal, salt water wetlands whereas the other categories represent freshwater systems. Lacustrine wetlands are associated with lakes; riverine wetlands are found along rivers and streams; and palustrine wetlands represent those wetlands that are referred to as marshes, swamps and bogs. Swamps are permanently flood areas dominated by herbaceous vegetation (trees and shrubs). Water can be present in swamps during all or just a small part of the year and they are mostly covered by plants. They often occur along river floodplains, in shallow water of lakes (e.g. papyrus swamps). Marshes are periodically or continually flooded wetlands characterized by non woody emergent herbaceous (non-woody) plants that are adapted to living in shallow water or in moisture-saturated soils. They are usually less than one meter in height. Bogs are characterized by spongy peat deposits, a growth of evergreen trees and shrubs.

Table 1. Wetland types **(Bacon, 1999)**

Type	Percentage
Marine	16.6
Estuarine	9.2
Lacustrine	23.8
Riverine	15.9
Palustrine	30
Artificial	10.5

3. Functions of wetlands

It is well known that wetlands provide a multitude of ecological benefits and services to human society as shown in Table 2. The capacity to provide goods and services is associated with their function whereas the benefits that humans derive from these functions are their services. Therefore, functions are related to the ecological processes of wetlands, and services are based on their functions. In general wetlands perform a number of functions such as hydrological, climatic, biodiversity, habitat, and water quality functions.

Wetlands fulfill a range of environmental functions and produce a number of products that are socially and economically beneficial to human communities (Dixon and Wood, 2003). They have been recognized as providing such specific benefits based on their hydrological and biological functioning (Bardeckil, 1991). It is the interactions of physical, biological and chemical components of a wetland, such as soils, water, plants and animals that enable the wetlands to perform an enormous variety of such vital functions (Lambert, 2003). As shown in Table 2, many wetlands have important societal values attached to them which can be subdivided into three categories as population, ecological, and global/regional values (such as nitrogen cycling) (Mitsch and Gosselink, 2007). At population level, according to Bardeckil (1991), Dugan (1990) and NRC (1992), wetlands provide important ecosystem services and life support economic activities to humanity such as food (e.g. fish), fresh water, fuel, timber, fur animals, waterfowls, recreational (opportunities for tourism and recreational activities), aesthetic (appreciation of natural features), spiritual and inspirational (personal feelings and well-being; religious significance), and at the ecosystem level wetlands moderate the effect of flood, serve as source, sink and transformer of a multitude of chemical and biological entities (including genetic materials). Economic benefits of wetlands include timber production, peat extraction, and recreation.

Table 2: Ecosystem services obtained from wetlands (MEA, 2005)

Services	**Comments and examples**
PROVISIONING	
• Food	Production of fish, wild game, fruits, and grains
• Fresh water	Storage and retention of water for domestic, industrial, and agricultural use
• Fiber and fuel	Production of logs, fuel wood, peat, fodder
• Biochemical	Extraction of medicines and other materials from biota
• Genetic materials	Genes for resistance to plant pathogens, ornamental species, and so on
REGULATING	
• Climate regulation	Source of and sink for greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes
• Water/ hydrological regulation	Groundwater recharge/discharge
• Water purification and waste treatment	Retention, recovery, and removal of excess nutrients and other pollutants
• Erosion regulation	Retention of soils and sediments
• Natural hazard regulation	Flood control, storm protection
• Pollination	Habitat for pollinators
CULTURAL	
• Spiritual and inspirational	Source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems
• Aesthetic	Many people find beauty or aesthetic value in aspects of wetland ecosystems
• Educational	Opportunities for formal and informal education and training
SUPPORTING	
• Soil formation	Sediment retention and accumulation of organic matter
• Nutrient cycling	Storage, recycling, processing, and acquisition of nutrients

In general, wetlands support rich communities and unique plants, birds, and fish (Brazner, 1997). According to Schuyt (2004), more than 30% of 603 Ramsar wetland sites examined had archaeological, historical, cultural, religious, mythical or artistic/creative significance. They are also known to sequester carbon and thus supporting climate-regulating functions worldwide (Carlson *et al.*, 2010). According to Wylynko (1999), one of the many ecological services of the healthy wetland ecosystems is their considerable potential for long-term carbon storage as they represent the largest component (14 %) of the global terrestrial biosphere carbon pool. As a whole, the diversity in functions that wetlands perform makes them valuable ecosystems because they have a very high ecological value, providing water and primary productivity upon which countless species of plants and animals depend for survival (Lambert, 2003; Schuyt, 2004).

In Africa, wetlands have also immense ecological importance and different socio-economic values. These include food crops supply through agriculture by draining, important sites for dry season grazing, resource extraction, raw materials supply e.g. reeds for thatching purposes, fish harvesting, source of medicinal plants and sites for tourist attraction and various traditional ceremonies. They are also part of the rural people's economy as they traditionally play an important role for rural communities through the provision of water, and other materials, for both humans and livestock. Wetlands have also significant benefits to the local communities such as livestock grazing, cultivation of crops, sources of resources e.g. clay soil, reeds, etc. for brick and pottery making, habitat for a variety of bird species, a sources of water for human use and livestock watering and other benefits as well (Figure 1).

Figure 1. Ecological and socioeconomic benefits of wetlands in Africa, Ethiopia

Although wetland ecosystems, as stated above, are one of the most productive ecosystems on earth, and although they have enormous societal and ecological benefits, the current ecological status of wetlands in general and their ecological functions and values to societal benefits in particular remain little understood and are insufficiently studied and recorded in Africa.

4. Climate change and its challenges on freshwater ecosystems

Freshwater habitats occupy 1% of the Earth's surface, and are hotspots that support 10% of all known species, and yet are exposed to the various pressures from human activities that have led to widespread habitat degradation, pollution, flow regulation and water extraction, fisheries overexploitation, and introduction of exotic species (Strayer and Dudgeon, 2010). These impacts along with anthropogenically induced climate change have caused severe declines in the range and abundance of many freshwater species so that freshwater ecosystems are now far more endangered than their terrestrial counterparts (Strayer and Dudgeon, 2010). These combinations of anthropogenic stress and climate change could be more deleterious than the effects arising from climate change alone (Angeler, 2007). Poff *et al*. (2002) has further strengthened the argument that there is strong consensus in the scientific community that freshwater ecosystems are particularly vulnerable to projected climate changes.

Impacts from climate change are inevitable in the decades ahead because the greenhouse gases (GHGs) that are now being released into the atmosphere will remain there for hundreds of years before being assimilated by natural processes, and consequently causing further warming (Wigley, 2005). These effects will depend on local, regional, and climatic conditions and will affect ecological responses across the biological hierarchy from organisms to communities (Angeler, 2007). Brooker *et al*. (2007) has also strengthen the issue stating that climate change is already impacting upon global biodiversity, and projections of climate change impacts indicate that very significant future changes will occur.

Anthropogenic climate change is having a significant impact on ecosystems (Rosenzweig *et al.* 2007). Freshwater ecosystems have been identified as among the ecosystems most vulnerable to climate change worldwide by changing temperatures and pattern of flow variability (Jin *et al.,* 2009, and Bates *et al.,* 2008). Lentic and lotic ecosystems are considered to be the most sensitive to climate change in a global-scale assessment (Sala *et al*., 2000). According to MEA (2005), of all ecosystems, freshwater aquatic ecosystems appear to have the highest proportion of species at risk of extinction by climate change.

Wetlands as an ecosystem are already under threat from various anthropogenic activities which are being aggravated by climate change. Climate change has the potential to alter water temperature, flow, runoff rate and timing, and the physical characteristics of the watershed. As a result of climate changes, warmer water temperatures in wetlands could intensify invasive species and also could stimulate the growth of algae, which could result in eutrophic conditions, declines in water quality, and changes in species composition (Lettenmaier *et al.,* 2008).

Climate change impacts on freshwater ecosystems will affect their capacity to remove pollutants and improve water quality; however, the timing, magnitude, and consequences of these impacts are not well understood according to Lettenmaier *et al.* (2008) whereas according to Wrona *et al*. (2008), the magnitude and extent of the ecological consequences of climate change in freshwater ecosystems will still depend largely on the rate and magnitude of change in three primary environmental drivers: the timing, magnitude, and duration of the runoff regime; temperature; and alterations in water chemistry such as nutrient levels, DO, and particulate organic matter loadings. But, climate change may profoundly affect hydrologic relationships in wetlands by altering inputs of precipitation and runoff and evapotranspiration outputs (Bardeckil, 1991). Climate change is expected to have numerous effects on freshwater systems, including changes to water clarity, water levels, pH, and surface water temperatures (Magnuson *et al.,* 1997). Tropical freshwater systems are particularly sensitive to global warming because of the high temperatures that characterize them, and as a result, a small increase in temperature can have significant effects on them (Magadza, 2011).

Yet, Bardeckil (1991) further stated that the greatest impacts on wetlands from climate change will not likely occur due to any direct change in temperature because the primary productivity of many wetlands may be enhanced through increasing temperatures. According to him and Carter (1987), the impacts are due to the climatic changes in water balance characterized by following parameters such as:

$$P + Sl + Gl = E + SO + GO$$

Where P represents precipitation; Sl -surface water inputs;Gl-groundwater inputs; E- evapotranspiration; SO-surface water output; & GO-groundwater output.

The climate change driven increased intensity or duration of precipitation further affects the wetland ecology due to sediment inputs. The case in point is the large areas of important wetland habitats of tropical areas such as the Pantanel of Brazil, the Inner Niger Delta in West Africa, the Okavango Swamp of Botswana, and the Grand Lac of the Lower Mekong are subject to sedimentation (Maltby, 1986). Even without changes in precipitation regimes, wetlands would be sensitive to climate changes as a result of increased potential evapotranspiration due to elevated temperatures (Bardeckil, 1991).

5. Effects of climate change on wetland functions

The resilience of many ecosystems could be threatened by an unprecedented combination of climate change associated disturbances such as flooding, drought, wildfire, etc. and other global change drivers such as land use change, pollution, fragmentation of natural systems, and overexploitation of resources (IPCC, 2007; CBD, 2009). The disturbances arise from three factors such as changes in land use, anthropogenic changes in global bio-geochemistry, and biotic additions and losses, and these three factors are the principal agents of global environmental change to interact and give rise to the two large-scale phenomena of climate change and loss of biodiversity (Vitousek *et al*., 1997). These global change drivers followed by global climate change have been identified as the major environmental disturbances of the future freshwater resources (Figure 2) (UNEP, 1999). Such disturbances in freshwater organisms vary in strength, frequency, predictability, duration, and spatial scale, and can deplete the biota, disrupt ecological processes, and redistribute resources (Lake *et al.*, 2000).

Scientific evidence has shown that humans have been a key driving factor in the dramatic changes seen in the earth's climate over the last 100 years (Smith *et al.,* 2010). The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) has determined that it is very likely (with 90% certainty) that anthropogenic emissions have contributed to global climate change (IPCC, 2007). Thus, climate change along with other human-induced changes in ecosystems composition and structure would lead to changes in the ecosystems values and services, as shown in Table 2, they provide (Campbell *et al.*, 2009; Rosenzweig, *et al*., 2007).

Wetlands are the main interface for moving nutrients, pollutants, and sediments from land to water (Kling *et al.,* 2003). Thus, according to these authors, decreased overland flow as a result of drying due to high temperature will decrease the inputs from uplands to wetlands, but will increase the retention of these substances in the wetlands. An eventual decrease in nutrient and carbon storage would be the result due to fluctuating water levels in wetlands combined with higher temperatures (Mulholland *et al.,* 1997). A future climate of higher temperatures and lower water levels is likely to increase the rate of organic matter decomposition and accelerate CO_2 releases to the atmosphere. Methane releases tend to increase with warmer temperatures and a rising water table (Updegraff *et al.,* 2001). Accordingly, changes in climate in both temperature and moisture affect the functioning of wetlands (Table 3) (Bardeckil, 1991). These changes in climate will have diverse effects on moisture availability, ranging from alterations in the timing and volume of stream flow to the lowering of water levels in many wetlands (Bates *et al.*, 2008). This could lead to changes in the critical goods and services of wetlands upon which human societies depend on.

6. Climate change and its challenge on the wetland ecosystems

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as, "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The naturally occurring greenhouse gases (GHGs) such as carbon dioxide, methane, nitrous oxide and water vapor trap the sun's heat and normally regulates the earth's temperatures. It is this natural phenomenon of this "greenhouse effect" that maintains livable temperatures on the earth).However, climate change associated with increased carbon dioxide and other greenhouse gases could significantly alter many of the world's wetland ecosystems like others (Virginia and Jon, 2000).

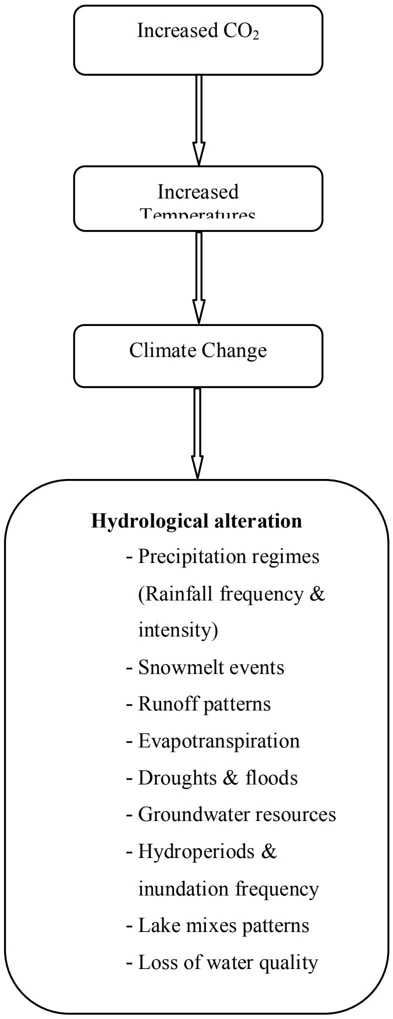

Figure 2. Conceptual model summarizing impacts in freshwater ecosystems that will arise as a result of disruption of natural hydrological functioning mediated by global climate change (Angeler, 2007)

Scientific evidence has shown that human-induced climate change, primarily through increases in greenhouse gas concentrations resulting from burning fossil fuels and deforesting large areas of land, is occurring (Solomon *et al.,* 2007). Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), tropospheric ozone (O_3) and nitrous oxide (N_2O) contribute 60%, 20%, 10% and 6% to global warming respectively and a minor contribution(4%) is made by chlorofluorocarbons (CFC) and volatile organic compounds(VOC) (Figure 3) (Dalal and Allen, 2008). They are the most problematic gases that amplify the natural green house effect. It is widely accepted by the scientific community that the earth is now undergoing a period of rapid climate change that is enhanced by anthropogenic atmospheric carbon enrichment during the past many years (Browne and Dell, 2007).

Global climate models predict that the global climate is warming and the variability in timing and type of precipitation are increasing. Observational evidence from Intergovernmental Panel on Climate Change (IPCC) reports has also demonstrated that the earth's climate is changing; hence, the global mean surface/ air temperature has increased by 0.6°C (0.4-0.8°C) (Gitay *et al.*, 2002), and by 0.74 ± 0.18°C (IPCC, 2007) over the last 100 years.

Based on Smith *et al.* (2010), the climate is changing faster than many ecosystems can adapt, and the rate of change is the key driver of the stress being placed on aquatic ecosystems. This increasing temperature will affect both the abiotic (e.g. physical mixing, water quality, etc.) and the biotic compartments (e.g. throughout physiology, specie range shifts, overall community metabolism, etc. (Lloréns, 2008). However, global climate change is a worldwide phenomenon with consequences not dispersed uniformly across the globe; consequently, different areas will see different effects (Smith *et al.,* 2010).

Climate change has the potential for affecting many wetlands by altering their basic hydrological regimes (Bardeckil, 1991), and nutrient inputs (CRM, 2007). Small alterations in the annual pattern of hydrological fluctuations may have dramatic impacts on wetlands (Bardeckil, 1991). As climate change alters, wetlands and species composition, unforeseen ecological changes are expected (e.g. harmful algal blooms or invasive alien species) that may threaten the goods and services wetlands provide to humans (Lloréns, 2008). In general, according to Browne and Dell (2007), climate change will affect wetlands through sea level rise, changes in hydrology and hydroperiod, increased water temperature; possible trophic changes, favoring more invasive species, changes in precipitation patterns, more intense weather events, land use changes, human water consumption patterns, etc.

Bardeckil (1991) has also stated that wetlands are dynamic systems and may be among the first ecosystems to respond to climate change. Yet, they play two important roles in ecosystem feedbacks to climate: as sinks and sources of greenhouse gases such as methane and carbon dioxide, and as regulators of climate (Jin *et al.,* 2009). According to MEA (2005), wetlands play important global roles in reducing the amount and rate of increase in atmospheric carbon dioxide, and are estimated to hold about 540 gigatons of carbon, which is 1.5% of the global carbon storage. Thus, destruction of wetland habitats can enhance global warming by the release of stored carbon to the atmosphere (Virginia and Jon, 2000).

Table 3. Changes in wetland ecosystems driven by climate change (Modified from Kling *et al.*, 2003)

Climate driven change	**Likely impacts on physical properties**	**Likely impacts on ecosystem properties**	**Intensifying or confounding variables**
Decreased summer water levels	Isolation and fragmentation within wetland complexes increase. Reductions in dissolved organic carbon result in less attenuation of UV-B radiation.	Habitat and migration corridors are reduced, as are hydrologic connections to riparian zones and groundwater recharge. Emergent vegetation and shrubs dominate plant communities. Amphibian and fish reproduction fails more often in dry years. Organisms with poor dispersal abilities become extinct.	Agricultural and urban development exacerbates fragmentation effects .
Warmer temperatures	Evaporative losses increase . fens and bogs store less carbon.	The rate of decomposition and respiration increase. Insects emerge earlier. Primary and secondary production per unit biomass increase when nutrients are not limited. Species with limited. thermal tolerances at the southern extent of the range become extinct.	Impervious surfaces increase water temperature . More competition from invasive species may accelerate extinctions.
Increased intensity and frequency of storms	Wetlands increase in extent .	Habitat area increases. Ground-nesting birds may be lost during floods.	Wetland losses from development reduce flood storage capacity .
Elevated atmospheric CO_2		Possible changes in leaf litter quality could impact aquatic food webs.	

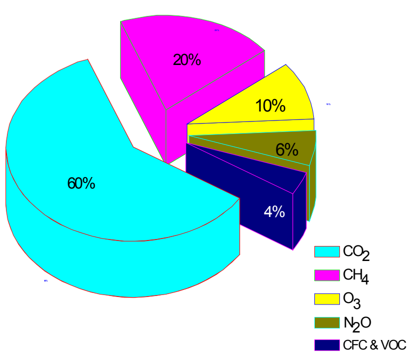

Figure 3. Percentage contribution of GHS to global warming (Dalal and Allen, 2008).

Wetlands cover a heterogeneous spectrum of aquatic habitats, widely recognized as biodiversity hotspots and key components of the global carbon budget (IPCC, 2002). Many studies have indicated that the critical climate drivers that determine the structure and function of the wetland ecosystems are the rate and magnitude of change in temperature and water availability from precipitation. Thus, the significant and persistent changes in both the mean and the variability of climate variables determine the impacts of climate change on wetlands. These effects range from the direct effects of the changes in climatic variables such as temperature, and precipitation to the indirect effects through interactions with non-climatic drivers like land and water use, and disturbances such as eutrophication, acidification, etc. Responses of wetland ecosystems to changes in climate involve complex interactions of biotic and abiotic components and processes. Such responses of wetlands to climate change are the result of a balance between changes in water regime, temperature, nutrient cycling, physiological acclimation and community reorganization (Oechel *et al.,* 2000). Yet, it is agreed that wetlands by themselves are also the good carbon sinks to mitigate the problems of greenhouse gas emissions (Virginia and Jon, 2000). Thus, restoration of wetlands and conservation of existing wetlands must be in place to be an important strategy for mitigating the anthropogenic origin of climate change.

7. Biodiversity in wetlands versus climate change

Biodiversity is defined as the variability among living organisms from all sources including diversity within species, between species and of ecosystems. Biodiversity is very important for every sphere of human existence and provides us with a vast range of products and services ranging from the food we eat, clean water, fuel and construction materials to fertile soils, and healing plants for medicines and not least, the clean air we breathe (MEA, 2005). Fauna and flora constitute an important component of the freshwater biota. In this regard, wetlands are rich in plant and animal biodiversity, and are sources of substantial biodiversity in supporting high concentration of birds, mammals, reptiles, amphibians, fish and invertebrate species. For example, of the 36,000 species of fish existing today in the world, more than 40% live in fresh water (Lambert, 2003). Individual wetlands can be extremely important in supporting high numbers of endemic species; for example, Lake Tanganyika in east central Africa supports 632 endemic fish and other animal species (Schuyt, 2004). It is also believed that more than 6,000 wetland plant species have been identified worldwide (Virginia and Jon, 2000).

However, numerous studies have observed that the impacts of global climate change are widely recognized as major threats to biodiversity and their habitats (IPCC, 2002; Hulme, 2005). It is being stated that an increase in CO2 will trap heat in the atmosphere causing a rise in wetlands temperatures that challenge wetland plants and animals (Kusler, 2006). Browne and Dell (2007) have also confirmed that sensitive wetland ecosystems can be significantly affected by relatively minor climatic changes in hydrology. Yet, it is observed that individual organisms survive within specific ranges of temperature, water, and chemical conditions. It is believed that climate change has an overall role in controlling these physical, chemical and biological conditions and processes, and species composition in ecosystems, affecting their ecological structure, function and biodiversity (Jin *et al.*, 2009). If organisms are exposed to unfavorable climatic conditions outside their normal environmental range, they must adapt or migrate, or they will perish (Lake *et al*., 2000; Poff *et al.,* 2002). For example, reduced precipitation in a given season may affect bird migration or nesting although mean precipitation and water level remain constant (Virginia and Jon, 2000). The water volume in a wetland directly influences ecosystem functioning by determining the extent of suitable habitat for species and many aspects of water quality (Lloréns, 2008).

Temperature and water are among the key variables in climate change that determine the distribution, growth and productivity, and reproduction of plants and animals (Bates *et al*., 2008). Studies indicate that lower water levels may lead to poorer environmental conditions to affect aquatic species. Climate change will also affect phenology, which in turn could affect the species population, plant-pollinator interactions and prey-predator dynamics (Campbell *et al.*, 2009). Keddy(2000) focusing on wetlands also stated that wetland plants and animals can significantly be affected at different stages of their life cycle if there is small increases in precipitation variability. In general, climate Change is already adversely impacting biodiversity at the ecosystem level through changes in distribution, composition, function, successional process and community dynamics, and values and services, and at the species level further changes in biodiversity are inevitable with further changes in climate (Campbell *et al*., 2009).

Wetlands are rich with many species of amphibians, small mammals, fishes, birds and aquatic plants including the many threatened and endangered species. The value of all wetlands as a habitat for these species depends on the size of the wetlands, diversity of vegetation, water quality, and soil conditions. However, all these abiotic and biotic factors can be affected by changes in climate. As a result of which the biodiversity of wetlands could in turn be affected by climate change like the rest of all other ecosystems. Bates *et al.* (2008) have confirmed that freshwater ecosystems are all highly vulnerable to the changes in climate and have shown changes in species composition, organism abundance, productivity and phenological shifts (including earlier fish migration) due to climate-related warming. As freshwater ecosystems, wetlands are often said to be the biodiversity hotspots, and their loss due to climate change could lead to significant extinctions, especially among amphibians and aquatic reptiles (Bates *et al.*, 2008). Based on Chapin *et al*. (2000), the proportion of the global number of fish, birds, mammals, and plants species that are currently threatened with extinction due to climate change is indicated in figure 4. However, according to Bates *et al.* (2008) assessment research report of all the ecosystems it is the freshwater ecosystems that have the highest proportion of species threatened with extinction due to climate change.

Animals and plants are already showing visible changes consistent with the climatic trends of the 20th century (Bates *et al*., 2008). Furthermore, according to the Intergovernmental Panel for Climate Change, up to 30 percent of the higher plant and animal species are likely to be at an increased risk of extinction if global average temperature increase exceeds 1.5 to 2.5 degree Celsius over present temperature (Campbell *et al.,* 2009). Studies indicate that many of the Earth's species are already at risk of extinction due to pressures arising from natural processes and human activities. Therefore, the potential impacts of human-induced climatic change can also add another pressures to the dynamism of wetlands (Bardeckil, 1991), and will further aggravate the effects of these pressures on these ecosystems (CBD, 2009; MEA, 2005), and on the loss of biodiversity especially for threatened and vulnerable species (Gitay *et al*., 2002). This will likely cause a reduction in biological diversity and in the subsequent goods and services that wetlands provide society (IPCC, 2002).

Strengthening this perception, Campbell *et al.* (2009) and Gitay *et al.* (2002) stated that the risk of extinction will increase especially for those that are already at risk due to factors such as slower life history trait, limited dispersal abilities, low reproduction rate, small population size and specialist and range-restricted species, limited climatic ranges, or occurrence on low-lying islands or near mountain tops.

In general, climate change will produce significant effects on the biodiversity of freshwater ecosystems, and is very likely to have both direct and indirect consequences on the organisms and the structure and function of freshwater ecosystems (Wrona *et al.,* 2008).

Wetlands in Africa are habitats for various aquatic and terrestrial organisms, and they could not also be beyond the impacts of the global climate change. Endemic fishes, birds and other life forms depend on these wetlands. Therefore, the impacts of climate change will have the loss effect on these resource rich wetland ecosystems, and therefore devastation to several endemic species and particularly to wetland dependent species.

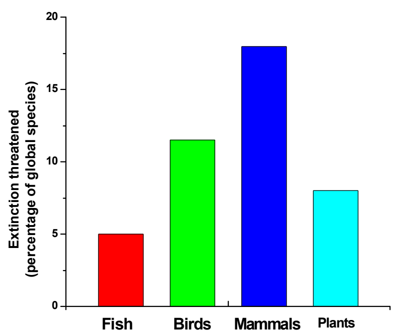

Figure 4. Global percentage of species currently threatened with extinction due to climate changes (as modified from Chapin *et al*., 2000)

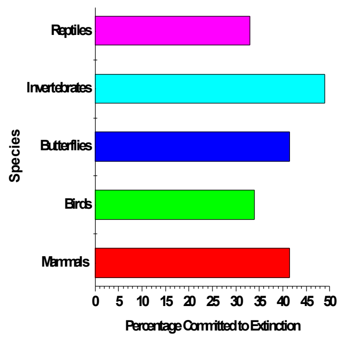

Figure 5. Average percentage of animal species lost in the Kruger National Park due to climate changes (as modified from Bates *et al.,* 2008).

8. Impacts of climate change on wetland fauna

As has been stated above, wetlands support high biological diversity, and are important life support ecosystems for migratory birds and other animals. However, endemic and economically important wetland animal species may be affected, and become rare, threatened or endangered as a result of climate change (Maltby, 1986). According to Bardeckil (1991), food fish, shrimp, oysters, waterfowl and fur bearing animals are those of economic importance wetland organisms that are potentially affected by climate change. For example, though it is not limited only to the wetland ecosystems, as a result of a global mean temperature increase of 2.5 - 3.0°C above the year 1990 levels in the Kruger National Park (South Africa) alone, mammals, birds, butterflies and other invertebrates, and reptiles would be committed to extinction (Figure 5), and in total, 66% of animal species would potentially be lost (Bates *et al.*, 2008).

The impacts of climate change on animal populations are likely to include both direct and indirect effects (Magadza, 2011). Direct effects of climate change to be those resulting from changes to a population's abiotic environment. Hence, direct effects of climate change on animal populations might include altered mortality or reproductive rates resulting from changes in ambient temperature, the frequency and severity of extreme weather events, and the availability of surface water. Indirect effects include those resulting from changes in a population's biotic environment, specifically the distribution and abundance of their resources, predators, and competitors. Because patterns of individual energy intake and expenditure represent the point of integration for abiotic and biotic influences, energetic approaches are uniquely suited to prediction of both direct and indirect effects of climate change.

In general, concerning the biological behaviors that make species most susceptible to climate change, IUCN has identified five groups of traits that are believed to be linked to increased susceptibility to climate change; these are specialized habitat and/or microhabitat requirements; narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle; dependence on specific environmental triggers or cues that is likely to be disrupted by climate change; dependence on inter-specific interactions that is likely to be disrupted by climate change; and poor ability to disperse to or colonize a new or more suitable range.

8.1. Invertebrates

Studies show that increasing temperature due to climate change will cause water quality deterioration that can have negative impacts on aquatic micro-organisms and benthic invertebrates. According to Campbell *et al.* (2009), an increase in temperature due to climate change may cause plankton communities and their associated food webs to likely cause changes in composition, which in turn changes in the distribution of fish and other aquatic organisms, with possibility of some species becoming extinct.

8.2. Fishes

As has been indicated in many studies climate change is warming the waters of the wetland ecosystems. This change in temperature will cause the wetland ecosystem to be in a different condition to which the existing species find it difficult to live in and survive (Poff *et al*., 2002). For example, when there is an increase in temperature (warming) and/or a decrease in precipitation due to climate change, the waterways connecting wetlands will be lost so that many fish species may also be unable to travel to other systems. Poff *et al*. (2002) has also stated that many of cold or cool water fish species will be affected by a rise in temperature because many of these species depend on wetlands as a nursery zone and would no longer be able to use these areas due to temperature increase.

Temperatures in aquatic ecosystems are closely coupled to air temperature (Meisner *et al*., 1988; Boyd and Tucker, 1998). Thus, it is obvious that an increase in air temperature is expected to be followed by similar increases in water temperature. For example, Northcote (1992) predicted that a 4°C increase in air temperature would result in a 3-8°C increase in the surface temperature of a 10m deep lake in British Columbia, Canada. According to Ficke *et al.* (2005) a change in water temperature will have cascading effects on wetland ecosystems and the fisheries that depend on them.

As freshwater fishes are all cold-blooded or "poikilothermic" animals that cannot regulate their body temperature through physiological means (Moyle and Cech, 2004), their physiological mechanisms are directly or indirectly environmental temperature - dependent at their specific location (Brio, 1998). This inseparable association to the water temperature makes fishes susceptible to even small-scale changes in environmental conditions (Ficke *et al.,* 2005) like other water dependent plants and animals as shown in figure 4. One such disturbance is the increase in mean global temperatures caused by the accelerated release of "greenhouse gases" such as CO_2, N_2O, and CH_4 as shown in Figure 3, largely from the combustion of fossil fuels (ACIA, 2004). An increase in water temperature due to climate change is therefore one of the "master variables" in freshwater systems that can affect all aspects of fish population by altering their physiological functions such as thermal tolerance, growth, metabolism, food consumption, reproductive success, and the ability to maintain internal homeostasis in the face of a variable external environment (Roessig *et al*., 2004).

Thus, global warming can affect fish populations through direct temperature effects on efficient metabolism, reproductive success, and disease resistance (Ficke *et al*., 2005). It can also alter the suitable physical habitat available to fishes. This is because oxygen solubility in water has an inverse relationship with water temperature (Kalff, 2000), i.e. oxygen solubility decreases with increasing water temperature. Further, Kalff(2000) confirmed that water at 0°C holds about 14.6 mg O_2/L , but water at 25°C can only hold about 8.3 mg O_2/L. This clearly indicates that warmer water holds less oxygen and increases the biological oxygen demand (BOD) while at the same time the amount of available oxygen (O_2) will be reduced because the aerobic metabolic rates of most cold-blooded aquatic organisms increase with temperature (Kalff, 2000). Increased incidence of hypoxia in freshwater systems is a likely result of climate change due to the decreased DO concentrations and increased biological oxygen demand that are associated with of increasing temperatures (Ficke *et al.,* 2005).

Thus, increases in water temperature due to climate change will result in increased oxygen demand, and can also increase the productivity of a body of water by increasing algal growth, bacterial metabolism, and nutrient cycling rates (Ficke *et al*., 2005). When these effects are coupled with the input of anthropogenic pollutants, temperature changes can accelerate the eutrophication process (Adrian *et al*., 1995) that could in turn affect the fish population. Climate change is also expected to affect fish populations through its influence on physical factors such as water chemistry and limnology (Ficke *et al*., 2005). The same authors have also further stated that most water chemistry parameters, including dissolved oxygen (DO) levels, pH, nutrient concentrations, and the toxicity of natural and anthropogenic pollutants are also affected by increase in water temperature.

8.3. Amphibians

As amphibians are cold-blooded animals, they are sensitive to habitat changes like other cold-blooded vertebrate animals. This is because their body temperatures and activity cycles are dependent on the presence of optimal environmental conditions. That is why amphibian populations are sensitive to changes and variability to their environments (Carey and Alexander, 2003). Lind (2008) has also stated that the timing of key ecological events for amphibians is influenced by environmental conditions such as water temperature, precipitation patterns, and the hydroperiod (length of time and seasonality of water presence. Beebee (1995) has also strengthened the Lind (2008) idea stating that the timing of reproduction (breeding/egg laying), metamorphosis, dispersal, and migration may shift in response to higher temperatures and changes in rainfall. Therefore, as temperatures warm and the availability of water in aquatic habitats become more variable, the activities of amphibians occur inconsistently with other ecological events like emergence of their insect prey and other. As a result they are likely to experience lower rates of growth and survival to metamorphosis. This is because many amphibians require aquatic habitats for their complete life-cycle i.e. egg laying and larval development. According to Lind (2008), the interaction of climatic change exacerbated factors that influence the amphibians' reproductive success rates and survival to metamorphosis are changes and variability in local environmental and habitat conditions; the phenology (timing) of life-requisite activities; interactions with emerging pathogens and invasive species; and interactions with other environmental stressors (e.g., chemicals).Studies in the United States have also indicated that many of the endangered amphibian species such as bog turtles need wetland habitats with a wide range of variability in moisture conditions for their survival. Therefore, it is understandable that any shift in their habitat conditions will have a dramatic effect on amphibians. For example, the extinction of some amphibians was detected in Costa Rica, Spain and Australia as a result of the combined effects of an increase in temperature (warming) and a decrease in rainfall (water stress) conditions in these countries (Pounds *et al.,* 2006).

8.4. Birds

The global climate change is not only causing impacts as water shortages, drought, species extinctions and extreme weather events, but also affects on every aspect of wetlands and waterfowl (Browne and Dell, 2007). Wetlands are habitats and stopping surfaces for many bird species. According to Mitch and Gosselink (2007), over 80% of migratory birds are dependent on wetlands as a stopping ground in their travels. However, water birds are also vulnerable to the impacts of climate change. Several aspects of climate change will affect not only the wetlands, but also the water birds that use them in a number of different ways (Browne and Dell, 2007).

Climate change can have effects on the timing and distance travelled during waterfowl migration (Browne and Dell, 2007). Furthermore, climate variability can also affect on the populations and changes to the range distribution of water birds and abundance indirectly through trophic level impacts on food availability (Butler and Taylor, 2005). Although the mobility and adaptability of waterfowl may allow them to avoid areas that are most heavily impacted by climate change, the sensitivity of shallow wetland habitats to the climatic changes may make alternative habitats scarce (Browne and Dell, 2007). Therefore, as wetlands are affected and get dried by climate change due to an increase in temperature and a decrease in precipitation, aquatic birds will lose stopping grounds. Bates *et al.* (2008) have also confirmed that drying of wetlands due to climate change will affect the migration success of birds that use wetlands as stopovers in their migration.

Many African wetlands are also stop over sites for migratory birds of the world. In this regard, the African Rift Valleys are the main ones. For example, Lake Hawassa of Ethiopia alone supports more than a hundred species of water birds, including local and Palearctic migrants, and the large population of Marabou storks (Figure 6) (Zerihun Desta, 2003).

Figure 6. Marabou storks(*Leptoptilos crumeniferus*) on the shore of Lake Hawassa of Ethiopia

9. Impacts caused by climate change on wetland flora

Like animals wetland plants are also affected by the change in the global climate change. A period of low water is required by certain species of wetland plant species to undertake reproduction (Markham, 1982), and a change in the seasonality of precipitation could adversely affect the reproduction of such plant species (Bardeckil, 1991).

Any increase in average temperature would also allow the dispersal of wetland plant species into new areas by various means especially those considered as weeds, thus altering the structure and composition of many wetland conditions (Bardeckil, 1991). According to him, the typical plants mentioned are noxious weeds such as water hyacinth (*Eichhornia crasspipes*), water lettuce (*Pistia stratiotes*), purple loosestrife (*Lythrum salicaria*) and African pyle (*Salvinia molesta*) that infest many wetland areas. For example, the water hyacinth (Figure 7), considered as a weed, grows so abundantly due to its rapid growth and lack of natural predators that it sometimes deprives aquatic wildlife of oxygen, causing serious environmental problems (Encarta, 2007). The reason why water hyacinths exist in the Lake Koka of Ethiopia might be due to the increased in nutrient inputs that can result in eutrophication, and as a result of eutrophication the invasion by water hyacinth(Eichhornia crassipes), free floating macrophytes, will be formed. Once formed, water hyacinth is known to cause a reduction on productivity of a lake's phytoplankton since the weed mats shade out any photoautotrophs (both phytoplankton and also submersed macrophytes) beneath them (Scheffer et al., 2003). Thus, it is a nuisance to alter the ecology within wetlands by changing species composition and biodiversity.

10. Conclusion

Wetlands have enormous socioeconomic values supporting human life in many ways as a source of water, food, feed, medicinal plants and other income generating activities.

Figure 7. Water Hyacinth (*Eichhornia crassipes*) in Lake Koka of Ethiopia

They have also environmental services like recharging and discharging underground water, hosting biological diversity, sequestering carbon, mitigating flood hazards, etc. It is also believed that billions of people worldwide receive benefits from the exploitation of various abiotic and biotic wetland resources. However, climate change is affecting the biodiversity of wetland ecosystems worldwide that is in turn affecting fishes, birds and other life forms that depend on wetlands. Thus, if wetlands are lost due to climatic changes, there will therefore be devastation to several endemic species and particularly to wetland dependent species. Studies further indicate that changes in climate are likely to be the main drivers of wetland biodiversity loss in future. Understanding the impacts of climate change on wetlands is therefore essential in order to make good environmental decisions about wetland ecosystems in the future. In order to develop adaptation and mitigation strategies for the conservation of wetland biodiversity during climate changes, it is also necessary to understand the impacts of climate change on biodiversity. Along with the various adaptation and mitigation strategies, reducing pressures on wetlands arising from human activities must also be considered as it helps to resist the impact that climate change will have on wetland ecosystems and the associated biodiversities in the future.

Hence, the conservation, management and wise use of wetlands are very important for mitigating and adapting the impacts of climate change on wetlands. It is important to recognize the important role of wetlands in climate change mitigation and adaptation. Their management must integrate adaptation strategies (actions that help ecosystems accommodate changes adaptively) and mitigation strategies (actions that reduce anthropogenic influences on climate) into overall plans. Hence, as practical means for mitigation and adaptation actions to the impacts of climate change, countries should recognize the climate related global problems on wetland resources and consider the need to put in place the conservation and wise use, restoration, and safeguarding the resilience and range of ecological functions of wetlands. Thus, policies need to consider the connectedness and interdependence of natural systems with human systems, and human systems have to become much more adaptable in the face of climate change. The management of wetlands must take into account the impacts of climate change. Accordingly countries should integrate environmental, economic, political and social policy, and planning as an approach in the management of wetlands. There needs to be a value shift towards a true sustainable development for militating against and adapting to climate change, as economic prosperity and human health and wellbeing depend on healthy natural systems.

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