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Review on the Role and Implications of Wetlands to Climate Change

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Introduction- Three of the world's greatest challenges over the coming decades will be biodiversity loss, climate change, and water stress (World Bank, 2008). Global climate change is undoubtedly the most pervasive, complex and challenging of the global environmental issues facing contemporary society and it affects all aspects of development. The effects of climate change are local and vary among systems, sectors and regions. Although many natural and economic sectors will be affected by climate change, impacts on agriculture and water availability will have the greatest potential to negatively affect the livelihoods of the poor in rural areas, as well as national economic growth in the least-developed countries, especially for the people of sub-Saharan Africa (SSA) (Roetter et al., 2002).

The high dependence of the economies and rural people of SSA upon rain fed agriculture, the prevalence of poverty and food insecurity and limited development of institutional and infrastructural capacities makes coping with natural climate variability a perennial challenge. This challenge is being magnified by global climate change (Cline, 2007; Lobell et al., 2008). Expanding agriculture leads to habitat loss and fragmentation, drainage of wetlands, and impacts on freshwater and marine ecosystems through sedimentation and pollution and is one of the greatest threats to biodiversity worldwide (World Bank, 2008).

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REVIEWONTHEROLEANDIMPLICATIONSOFWETLANDSTOCLIMATECHANGE

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I. Introduction

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a) *Green House Gases (*GHGs*) and Global Warming*

Increasing concentrations of GHGs in the earth's atmosphere are expected to warm the earth and cause other, less easily predicted, changes in climate and finally leads to what is so called Global warming (Lal, 2004).Global warming refers to climate change that causes an increase in the average temp of the lower atmosphere. It can have many different causes, but it is most commonly associated with human interference, specifically the release of excessive amounts of GHGs such as $C0_2$, CH_4, nitrous oxide (N_2O), SO_2, water vapour, and fluorinated gases, act like a GHG around the earth. This means that they let the heat from the sun into the atmosphere, but do not allow the heat to escape back into space. The more GHGs there are, the larger percentage of heat that is trapped inside the earth's surface which leads to what is called global warming (Howard, 2003).

Human activities, especially the burning of fossil fuels such as coal, oil, and gas, have caused a substantial increase in the concentration of CO_2 in the atmosphere. Potential adverse impacts include sea-level rise; increased frequency and intensity of wildfires, floods, droughts, and tropical storms; changes in the amount, timing, and distribution of rain, snow, and runoff; and disturbance of coastal marine and other ecosystems. Rising atmospheric CO_2 is also increasing the absorption of CO_2 by seawater, causing the ocean to become more acidic, with potentially disruptive effects on marine plankton and coral reefs. Technically and economically feasible strategies are needed to mitigate the consequences of increased atmospheric CO_2. However, existing CO_2 uptake mechanisms (carbon "sinks") are insufficient to offset/ compensate/ balance/ counteract the accelerating pace of emissions related to human activities (USGS, 2008).

b) *Wetlands*

Wetlands are ecosystems or units of the landscape, ecologically situated at the interface between land and water and they optimize the attributes of both terrestrial and aquatic ecosystems. They are among the world's most biologically productive and diverse ecosystems. However, this transitional status contributes to wetlands being among the most threatened of the Earth's natural environments. Traditionally perceived as wastelands, wetlands have a long history of being drained and converted to other "productive" uses (Abebe & Geheb, 2003). The Ramsar Convention recognizes five major wetland systems (Ramsar Convention Bureau, 1997), while others identify up to seven main groupings (Dugan, 1990). The major Ramsar groupings are: Marine (coastal wetlands); Estuarine (deltas, tidal marshes, and mangroves); Lacustrine (lakes and associated wetlands); Riverine (rivers, streams and associated wetlands);and Palustrine (marshes, swamps and bogs). The Ramsar Convention on Wetlands provides the most universally comprehensive definition of wetlands as: "*areas of marsh, fen, peat land or water, whether natural or*

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artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (Ramsar, 1998).

Wetlands occur in every country, from tundra to the tropics. While the global extent of wetlands is not known exactly, the World Conservation Monitoring Centre has suggested an estimate of about 570 million ha, roughly 6 per cent of the Earth's land surface (Maltby, 1986; WCMC, 1992).

According to World Bank (2008), Ecosystems are not all equal either in their value for biodiversity conservation or their role in carbon storage and other ecosystem services. Wetlands provide many ecosystem services that are critical to reduce the vulnerability of communities to climate change in general and to extreme weather events in particular. Protecting existing wetlands and restoring degraded wetlands provides an opportunity to enhance mitigation actions. Peat lands and marshes contain large stores of carbon. In recent decades, drainage and conversion to agricultural lands and climate change has changed peatlands from a global carbon sink to a global carbon source. Avoiding degradation of peatlands, swamps, and wetlands is a beneficial mitigation option.

c) *Wetland Degradation, Conservation Efforts and their current status*

Wetlands encompass a significant proportion of the area of the planet and the majorities are utilized by people for some or other purpose. Many of these uses are sustainable and are compatible with the concept of conservation and wise use of wetlands. Many other activities associated with economic, urban and water resources developments characteristically lead to permanent loss of wetland area and degradation of wetland quality and function (Pritchard, 2009).

Degradation of wetlands and disturbance of their anaerobic environment lead to a higher rate of decomposition of the large amount of carbon stored in them and thus release GHGs to the atmosphere. Therefore, protecting wetlands is a practical way of retaining the existing carbon reserves and thus avoiding emission of carbon dioxide and GHGs (Shalu et al, 2009; Yarrow, 2009).

According to Moser *et al*. (1996) report *"the world may have lost 50% (half of) of the wetlands as a result of increasing pressure for conversion to alternative land use particularly drainage for agricultural production is the principal cause.''*

Yarrow (2009) also said that agriculture and development are the main/principal causes for the destruction and degradation of wetlands. We have already lost 50% globally and still losing wetlands, especially in developing countries and climate change will become one of the major drivers of ecosystem loss during this century and will intensify the impacts of the other drivers.

General strategies for land and water management practices adopted to reduce the impacts of climate change on wetlands include;better control the drainage of wetlands,prevent additional stresses and fragmentation,create upland setbacks and buffers, control exotics,protect low flows and residual water, control extraction of peat,restore and create wetlands, conduct stocking and captive breeding and conduct regional inventories and prepare management plans for wetlands at great risk from climate change (Rubey, 2010;and Kusler,2006).

d) *The Global Importance of Wetlands (Values and Functions)*

There is a broad and growing recognition that wetlands are critically important ecosystems that provide globally significant environmental, social and economic benefits. Among the most biologically productive of ecosystems, they support exceptional levels of biodiversity, purify and moderate water resources and provide food, fiber and water security for local communities (Ramsar, 1997; Woodward&Wui, 2001).

As in Ramsar STRP (2005); Pritchard (2009); Ramsar (1997); Wetlands deliver a wide range of critical services. These include food, fibre, water supply, water purification, regulation of water flows, coast protection, carbon storage, regulation of sediments, biodiversity, pollination, tourism, recreation and cultural services. Their benefits to people are essential for the future security of humankind, and this depends on maintenance of their extent, natural functioning and ecological character. Increasing demand for and over-use of, water is jeopardizing human well-being and the environment. Access to safe water, human health, food production, economic development and geopolitical stability are made less secure by the degradation of wetlands, driven by the rapidly widening gap between water demand and supply.

In Ramsar (1997): wetlands are important, and sometimes essential, for the health, welfare and safety of people who live in or near them. Among the world's most productive and biologically and functionally diverse environments, they provide a wide array of benefits. The interaction of physical, chemical and biological components of wetlands, which optimizes the attributes of both terrestrial and aquatic ecosystems, enables wetlands to perform many ecosystem functions, for example :water storage; storm protection and flood mitigation; shoreline stabilization and erosion control; groundwater recharge (the movement of water from the wetland down into the underground aquifer); groundwater discharge (the movement of water upward to become surface water in a wetland); water purification; retention of nutrients; retention of sediments; retention of pollutants; and stabilization of local climate conditions, particularly rainfall and temperature.

Wetlands provide tremendous economic benefits, water supply (quantity and quality); Fisheries; Agriculture, through the maintenance of water tables; Timber production; Energy resources, such as peat and plant matter; Wildlife resources; Transport and Recreation and tourism opportunities (Ramsar,1997).

As in Ramsar World wetlands day (2009);and MEA (2005);Wetlands deliver a wide range of ecosystem services that contribute to human well-being, such as fish and fiber, water supply, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, and increasingly tourism. Wetland ecosystems, including rivers, lakes, marshes, rice fields, and coastal areas, provide many services that contribute to human well-being and poverty alleviation. Some groups of people, particularly those living near wetlands, are highly dependent on these services and are directly harmed by their degradation. Two of the most important wetland ecosystem services affecting human well-being involve fish supply and water availability.

As in MEA(2005), and Woodward &Wui (2001)Although the influence of a wetland on the hydrological cycle is site-specific; Wetlands deliver a wide array of hydrological services—for instance, swamps, lakes, and marshes assist with flood mitigation, promote groundwater recharge, and regulate river flows but the nature and value of these services differs across wetland types. Wetlands provide various hydrological services as follows: gross water balance, flow regulation, flood-related services, pollution control and detoxification, groundwater services and river flow and hydrological regime variability.

II. Wetlands and Climate Change

Wetlands are vital parts of the natural landscapes whose biodiversity and ecosystem services on which humans depend, are threatened by the likely impacts of climate change (Ramsar, 2009). Globally, the negative impacts of climate change on wetland systems are expected to outweigh the benefits (Bates et al, 2008). Degradation and loss of wetlands make climate change worse and leave people more vulnerable to climate change impacts such as floods, droughts and famine. Many climate change policy responses for more water storage and transfers, as well as energy generation, if poorly implemented, may deleteriously impact on wetlands. Climate change is increasing uncertainty in water management and making it more difficult to close the gap between water demand and supply. We will increasingly feel the effects of climate change most directly through changes in the distribution and availability of water, increasing pressures on the health of wetlands. Restoring wetlands and maintaining hydrological cycles is of utmost importance in responses for addressing climate change, flood mitigation, water supply, food provision and biodiversity conservation (Ramsar, 2009 and Patterson, 1999).

Wetlands are among the ecosystem which will be most affected by even small changes in climate and resulting changes in hydrologic regimes such as sea level rise and decreased surface and ground water level.Many wetlands will be destroyed,rare and endangered plants and animals will be threatened. Some of the climate change factors that will affect wetlands are as follows; Increase in oxygen, increase in air,water and soil temp, changes in the amounts and timing of precipitation, intensification of climatological events, lengthened growing season in northern latitudes and sea level rise (Kusler,2006 & Rubey,2010).

a) *The Impacts of Climate Change on Wetlands*

Rubey(2010),Kussler(1999),and Kussler(2006); listed the following seven likely impacts of climate change factors on wetland ecosystems:

Increased productivity due to increased Co_2: Increased $C0_2$ will increase the primary productivity of most wetland plants except were sunlight,precipitation,or temprature is a limiting factor.Increase in primary productivity would enhance the habitat value of some wetlands although some shift in plant and animal species might also be expected and variations in responses.There are indications that this increased productivity will also result in increased methane emissions.

1. *Wetland changes due to decreased frosts*: The natural ranges of both natural and invasive wetland plant species are killed by frost actions.
2. *Wetland changes due to decreased precipitation*: Impacts will be particularly great where precipitation remains steady or decreases.Increases in temprature combined with reductions in precipitation will likely reduce surface and ground water levels in wetlands,destroying or reducing in size many wetlands.Lowered water levels will result in release of carbon and methane.
3. *Wetland changes due to increased precipitation*: Increased precipitation will result in increased ground water levels and increased water levels in wetlands and lakes. Shifts in wetland type may also occur with associated vegetation changes. This will likely to further result in:an increase in size of some freshwater wetlands due to the inundation or saturation,an increase in the number of depressional,flats,lake fringe,riverine,and slope wetlands(i.e.some will appear where they have not

been before) and a shift in wetland type and associated vegetation and fauna.

4. *Wetland changes due to an increase in severe Meteorological events:* All wetland systems are,to a greater or lesser extent,already subject to disturbance by extreme rainfall,flooding,and high winds.Increased frequency of extreme events may,however,cause irreversible damage to some wetland systems that are already stressed.Extreme events may also combine with sea level rise to increase shoreline erosion and land loss in coastal areas.
5. *Wetland changes due to sea level rise:* Projected sea level rises of 0.09 to 0.88 meters by 2100 combined with coastal subsidence in some areas will likely have severe impact on coastal and estuarine wetlands.There will be wetland losses where there is insufficient plant growth and sediment deposition to equal sea level rise and coastal or estuarine wetlands can not migrate inland.So that Rapid,substantial changes in sea level pose significant threats to coastal and estuarine wetlands.
6. *Wetland changes due to increase in temprature:* Increased air,water and soil temprature could have both direct and indirect impacts upon wetland plants and animals.The IPCC has concluded more generally that the "composition and geographic distribution of many ecosytems will shift as individual spp respond to changes in climate,there will likely be reductions in biological diversity and in the goods and services that ecosystems provide."(IPCC,2007).Temp increases will likely result in the melting of permafrost,increased decomposition rates,and releasing Co_2 and changing methane and nitrous oxide emissions and creating open water wetlands or aquatic ecosystems and there will be significant indirect effects of temp,evaporation,and transpiration increases.These will likely result less runoff (unless compensated by increased rainfall),less infiltration,and lowered ground water levels.

The degradation and loss of wetlands is more rapid than rates for other ecosystems (Ramsar STRP, 2005). Similarly, the status of both freshwater and, to a lesser extent, coastal species is deteriorating faster than that of species in other ecosystems. These trends have primarily been driven by land conversion and infrastructure development, water abstraction, eutrophication, pollution and over-exploitation. There are a number of broad, interrelated economic reasons, including perverse subsidies, why wetlands continue to be lost and degraded. This is leading to a reduction in the delivery of wetland ecosystem services, yet demand for these same services are projected to increase (Pritchard, 2009, Ramsar STRP, 2005, Lar, 2007)).

According to Kussler(2006),and Rubey(2010) Wetland ecosystems will be more severely impacted by climate change (in comparison with many terrestrial ecosystems) for three several reasons:

- Flora and Fauna in wetlands are especially sensitive to small,permanant changes in water levels while similar small changes in water levels often have less impact upon rivers,streams,and lakes.
- Wetlands have often been fragmented and cutoff hydrologically and ecologically from other wetlands and aquatic ecosystems by dams, dikes,fills, roads, drainage, and other landscape level alterations.Due to this fragmentation,wetland plants and animals can not naturally "migrate"to other locations over time in response to temperature and water level changes. Similarly, many coastal or estuarine wetlands will be unable to move inland in response to sea level rise,due to construction of dikes,levees,fills,or other development which fix the landward boundary.
- Many wetlnads are already severely stressed due to hydrlogic changes,water pollution,changes in sediment regimes,and other activities of mankind.These stresses have lowered biodiversity in wetlands. Reduced numbers of types of plants and animals makes the wetlands more vulnerable to small changes in temperature and water regimes.
- Impacts will vary depending upon the types,magnitudes and rate of changes in temperature, precipitation, hydroperiod, and other factors and the plant and animal spp in a wetland.

b) Types of Wetlands that will be most affected by Climate Change

Rubey (2010), Roulet (2000), and Kussler (2006), listed seven wetland types that are likely to be substantially impacted by climate change:

1. *Coastal and Estuarine wetlands*:coastal and estuarine wetlands may be destroyed if sea level rise exceeds the rate of deposition and inland migration is not possible.
2. *Tundra(permafrost) wetlands and other open tundra wetlands*:Areas of permafrost wetland may be melted and converted to open water by temp increases.Water levels in other open peatlands may be invaded by boreal forsets.
3. *Wetland boreal forests*:Climate change is likely to have significant impact upon boreal forests through the loss of boreal forests,invasion of tree lines into tundra areas,increased fire,and increased pest outbreaks.A combination of temp increase and the lowering of groundwater tables may expose peat and organic soils to oxidation.However,increases in C02 may also result in increased forest vegetation.
4. *Alphine wetlands near the tops of mountains*:Even small amounts of warming may destroy "relic"plant

and animal spp in alpine wetlands since there will be little opportunity to migrate to other locations.

5. *Prairie potholes:*Reductions in wetland size and the disappearance of some wetlands can be expected with substantial increases in temp and only modest increases in precipitation in the prairie pothole region.Waterfowl production may be reduced with the reduced precipitation in the spring or fall and reduced water levels when migrations occur even if overall precipitation levels do not change.
6. *Playas,Vernal pools,other seasonal wetlands:*Temporary,shallow wetlands will be particularly sensitive to increases in temp and increased evaporation and transpiration.They will also be sensitive to decreases or increases in precipitation.
7. *Other depressional,slope,flats,river,and lake fringe wetlands:*Some drying,decrease in wetland size,and conversion to uplands can be expected for most of freshwater wetlands where precipitaion is decreased or remains steady while temp are substantially increased since these wetlands are very sensitive to small changes in groundwater levels.However,there may be exceptions such as the greatlakes where lowering of water levels may expose wide flats or benches which will be colonized by wetland vegetation.

c) *Wetland functions that will be most affected by Climate Change*

The impact of climate change on the services and goods wetlands provide for society will vary by type of wetland and by function/value.As suggested by (Rubbey, 2010; Kussler, 2006 and Smith,1995), the various wetland functions that may be most affected with changing climate are listed below

1. *Fisheries production:* with rising water temprature in lakes,streams and wetlands,reduction in the numbers of cold water fish(e.g.trout) and increase in warm water fish such as bass may be expected.With rapid sea level rise and destruction of salt marshes which can not migrate inland,reduced yields of ocean and estuarine fish species which depend upon coastal and estuarine wetlands for rearing or food chain support may also be expected.
2. *Shellfish production:* a reduced in the size of coastal and estuarine wetlands and adjacent “flats”and increases in water depths will reduce shellfish production.
3. *Waterfowl production:* increased temprature with onlyslightly increased precipitation in the praire pothole region will convert some wetlands to dry land,reduce others in size,and shift marshes with standing water to saturated during the spring and fall may adversely affect waterfowl even if precipitation remains constant.
4. *Habitat for rare and endangered species:* the role of wetlands throughout the nation as habitat for rare and endangered species may be compromised wherever species are dependant upon specific hydrologic and temprature conditions and flora and fauna cannot migrate to new locations.This is particularly true for systems that are already stressed by water pollution and human-induced alterations and are highly fragmented.Species extinctions and Biodiversity loss are probable; species range and ecosystems structures will also change.Further damage due to invasions by exotic species with northward extension of ranges is also likely.
5. *Food chain support:* destruction of coastal and estuarine wetlands by rapid sea level rise would result in loss of detritus and other food chain support for estuarine and coastal fish,shellfish,and other fauna. On the other hand,some increase in food chain support might be expected in some situations due to increased primary productivity resulting from increases in $C0_2$(assuming that there are not other limiting factors).
6. *Water quality buffering and pollution control:* destruction of coastal and estuarine wetlands due to sea level rise would result in loss of their water quality pollution control functions.Similar losses would occur where depressional,slope,flats,and river and lake fringe wetlands are diminished in size or destroyed by lowered ground or surface water elevations due to reduced precipitation and/or increased temprature
7. On the other hand,some increase in water quality buffering could occur for freshwater wetlands due to $C0_2$ induced increses in the density and amounts of vegetation (assuming adequate water levels to maintain wetlnads and lack of other limiting factors).Some wetlands would increases in size and numbers in areas of increased rainfall.
8. *Wave attenuation and erosion control:* the destruction of coastal and estuarine wetlands by sea level rise would expose back-lying lands to added increased density of wetland trees and other vegetation due to increased $C0_2$ might also enhance the wave attenuation and erosion control functions of surviving estuarine,coastal,and freshwater wetlands.
9. *Production of forestry products and natural crops:* increased $C0_2$ will result in increased growth of trees and other natural wetland crops such as wild rice,and cranberries if such increases are not ‘’limited’’by phosporous,nitrogen,or other limiting factors.Nevertheless,there could also be loss of coastal,estuarine,and freshwater wetlands and the forestry products they produce by sea level

rise,increased severe meteorological events,and decreased precipitation in some instances.For example,bottomland hardwoods are particularly susceptible to hurricanes.

10. *Carbon storage and sequestering:* increased $C0_2$ could result in increased plant growth in wetlands and the potential for increased carbon sequestration where there are not other limiting factors.But,the carbon storgae and sequestering role of tundra wetlands could also be reduced by the melting of permafrost,drainage and the subsequent release of $C0_2$ and other atmospheric gases.Carbon storage and sequestering by northern,nonpermafrost peatlands would also likely be reduced by a combination of increased temp and reduced ground and surface water levels,causing oxidation of the peat.
11. *Flood conveyance and storage:* the flood conveyance and flood storage roles of wetlands for major (infrequent) flood events would probably not be substantially affected by climate change since these roles depend more upon wetland configu-ration and size than biotic factors.However, increased vegetation growth due to increases in $C0_2$ might reduce flood conveyance capacity for riverine wetlands by increasing the ''roughness'' of wetland-dominated floodplains. Sediment loadings due to increased severe meteoro-logical events could also fill depressional, riverine and other wetland types with resulting reduction in flood conveyance and flood storage capability.

III. The Role of Wetlands on Climate Change

According to Shalu et al (2009), Wetlands are among the most important natural resources on earth that provide a potential sink for atmospheric carbon but if not managed properly, they become a source of green house gases.

Wetlands are vulnerable to human-induced climate change but, if managed well, their ecosystems and biodiversity play a key role in the mitigation and adaptation of climate change and will be important in helping humans to adapt to climate change through their critical role in ensuring water and food security. As a result, caring for wetlands is considered as of the solution to climate change (STRP, 2009; IPCC, 2007).

Wetland ecosystems are essential for climate change adaptation. Water and well-functioning wetlands play a key role in responding to climate change and in regulating natural climatic processes (through the water cycle, maintenance of biodiversity, reduced GHG emissions, and buffering of impacts). Conservation and wise use of wetlands help to reduce the negative economic, social and ecological effects (Ramsar, 2009).Wetlands lessen the impact of extreme weather events due to climate change:–healthy wetlands absorb floods, decreasing the incidence and severities of catastrophic flooding–coastal wetlands protect ecosystems and communities from storms and sea-level rise–Wetlands are crucial freshwater reservoirs in regions where climate change increases drought (Schlesinger, 1997).

a) *Wetlands as Sources and Sinks*

While wetlands constitute a major carbon reservoir, they can function as either greenhouse gas sinks or sources depending on their type, their use and ambient conditions. Some wetlands are character-ristically sources and others are sinks. Some have a different role at different times as determined by hydrology. In some wetland types there is a tradeoff/substitution/exchange between being a carbon sink and a methane source (Pritchard, 2009). Carbon sinks are ecosystems (the main ones being soil, oceans and forests) that store CO_2 in water, sediment, wood, roots, leaves and the soil.

Oceans are natural CO_2 sinks, and represent the largest active carbon sink on Earth, consuming 93% of the world's CO_2. CO_2 dissolves in sea water before being transported in organic and inorganic forms from the sea surface to the ocean's interior. Currently, approximately one third of anthropogenic (man made) emissions are estimated to be entering the ocean (Earth Watch Institute, 2007).

i. *Greenhouse Gas Emissions*

Wetlands play a crucial role in regulating exchanges to/from the atmosphere of the naturally-produced gases involved in "greenhouse" effects, namely water vapour, carbon dioxide, methane, nitrous oxide (all associated with warming) and sulphur dioxide (associated with cooling). They tend to be sinks for carbon and nitrogen, and sources for methane and sulphur compounds, but situations vary widely from place to place, from time to time, and between wetland types (Ramsar, 2009). Wetland land-use, and discharge, treatment and re-use of waste water can all have profound effects on emissions and hence on the success of mitigation and adaptation strategies. The most robust generalization is that degradation and disturbance of naturally-functioning wetlands is a major cause of increased carbon emissions (Ramsar Secretariat et al, 2007).

One of the best documented dimensions of this relates to peat lands, where the delicate balance between anaerobic production and aerobic decay causes them readily to switch from carbon sinks to sources following human interventions. Peatland degradation is now a major and growing cause of anthropogenic carbon dioxide emissions, with drainage, fires and extraction (Parish et al, 2008;Patterson &Kussler,1999).

ii. *Carbon Sequestration*

It is the term describing processes that remove carbon from the atmosphere. To help mitigate climate change, conservation management to enhance natural sequestration processes is being explored (Earth Watch Institute, 2007).The term is used to describe both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations (USGS, 2008). A variety of means of artificially capturing and storing carbon as well as of enhancing natural sequestration processes, are being explored. The main natural process is photosynthesis by plants and single-celled organisms (Howard, 2003).

The world's oceans are the primary long-term sink for human-caused CO_2 emissions, currently accounting for a global net uptake of about 2 gigatons of carbon annually. This uptake is not a result of deliberate sequestration, but occurs naturally through chemical reactions between seawater and CO_2 in the atmosphere. While absorbing atmospheric CO_2, these reactions cause the oceans to become more acidic. Laboratory and field measurements indicate that CO_2-induced acidification may eventually cause the rate of dissolution of carbonate to exceed its rate of formation in these ecosystems. The impacts of ocean acidification and deliberate ocean fertilization on coastal and marine food webs and other resources are poorly understood (USGS, 2008, Earth Watch Institute, 2007).

iii. *Carbon Capture (CC) and Storage*

It is a plan to mitigate climate change by artificially capturing $C0_2$ from large point sources such as power plants and subsequently storing it away safely instead of releasing it into the atmosphere (Howard, 2003).

It is the interplay/interaction between water logging, high plant productivity, sequestration of carbon in the soil, and production of carbon dioxide and methane that makes wetlands one of the most important terrestrial surfaces in climate change; complicated by the fact that different wetland types have markedly different greenhouse gas and carbon balance profiles (Patterson, 1999). Climate change may itself of course also affect the wetland carbon sink, although the direction of the effect is uncertain due to the number of climate-related contributing factors and the range of possible responses (Ramsar, 2009). Sources estimate that wetlands account for about one-third of terrestrial carbon stores (Ramsar, 1997). There is however a dearth of consolidated information on the role and importance of different types of wetlands and in different parts of the world in carbon sequestration and storage. It has been claimed that restoration of wetlands offers a return on investment up to 100 times that of alternative carbon mitigation investments (Ramsar Secretariat et al, 2007).

Peatlands are the most important long-term carbon store in the terrestrial biosphere. Although covering only 3% of the world's land area, peatlands contain as much carbon (400-700 Gt) as all terrestrial biomass, twice as much as all global forest biomass, and about the same amount as is in the atmosphere (Parish et al, 2008). Intact peatlands can store up to 1,300 tons of carbon per hectare, compared to 500-700 tons in old-growth forests. They account for the majority of all carbon stored in wetland biomes worldwide. This would, if all converted to carbon dioxide, increase the atmospheric concentration of CO2 (Pena, 2008).

Although peatlands are known to be an overall sink for carbon, and in many regions are still actively sequestering it (Ramsar, 2009), initial studies produced a confusing picture of this, with some sites appearing as carbon sinks and others as sources.

Peatland degradation is now a major and growing cause of loss of global carbon storage capacity. Any action that would avoid degradation of these wetlands would therefore be a beneficial mitigation option. Mitigation is the most that can probably happen in the short-term as the current plant species are largely incapable of increasing production in response to higher temperatures and atmospheric CO_2 concentrations (Erwin, 2009), Wetlands International (2008b) report similar results indicating that relatively minor investments have significant emission reduction impacts. Carbon sequestration benefits should result from restoration of areas of other wetland types too (e.g. mangroves, salt marshes, floodplain marshes).

CH_4 emissions from wetlands are controlled by water table position and soil (peat or sediment) temperature. A drop in water table position decreases CH_4 production and increases CH_4 oxidation, thereby decreasing emissions. Depending on water table position, emission of CH_4 from peat lands is between 0.5 and 50 g CH_4-C/m2/yr. (Hengeveld and Beaulieu, 1999).

iv. *Sea level rise*

Coastal wetlands will play a major part in strategies for dealing with problems created by sea level rise. Mangrove forests, coral reefs and tidal flats can attenuate wave-energy and contribute to coast defences in a more cost-effective way than hard defences, providing enhanced protection against increasingly frequent storm-events as well as rising sea levels (Wetlands International, 2008a).

In addition to physical damage, inundation (causing loss of productive or otherwise valuable areas), upstream and underground salinisation (causing loss of freshwater supplies) and other impacts can also be

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lessened through maintenance or restoration of naturally-functioning coastal hydrology and wetland ecosystems. Moreover, land-use change and hydro-logical modifications anywhere in a water catchment or river basin may have downstream impacts which interact in the coastal zone with sea level rise risk factors. Integrated planning (as advocated in many technical and policy guidance materials adopted over the years under the Ramsar Convention in particular) is essential here (Bates et al, 2008).

b) Wetland Carbon Stocks

Wetlands cover 6 per cent of the world's land surface but contain 14 per cent of the terrestrial biosphere carbon pool. There is a significant amount of carbon stored in wetland soils,peats,litter,and vegetation(globally estimated 500-700GT).The amount stored in wetlands may approach the total amount of atmospheric carbon (estimated at 753GT) (IPCC, 2002).Of various wetland types, peatland has been recognized worldwide as highly important for carbon storage since it accounts for nearly 50% of the terrestrial carbon storage with only 3% cover of world's land area i.e. Peatlands contain the most carbon (Guo&Gifford,2002,Multiby&Immirz,1993).However,coastal wetlands,praire potholes,river and lake fringing wetlands and other wetland types may also contain significant amounts of carbon. In addition, coastal salt marshes and mangroves are considered the most important marine ecosystems for carbon sequestration. When peat lands are included, as is the case in the Ramsar wetland definition, wetlands represent the largest component of the terrestrial biosphere carbon pool (Dixon and Krankina, 1995).

The terrestrial biosphere is estimated to contain a carbon pool of 1943 Gt. Wetlands constitute a large global C reservoir at 230 Gt, exceeding agroeco systems (150 Gt) and temperate forests (159 Gt). Significant peat deposits are co-located with forests at high latitudes and are accounted for in the forests/tundra total of 559 Gt (Dixon and Krankina, 1995). According to Zoltai and Martikainen (1996), peatlands hold soil carbon stocks of 541 Gt, which accounts for 34.6 per cent of total terrestrial carbon. When peatlands are segregated, they account for one half times more carbon than tropical rainforests (Immirizi and Maltby, 1992). Per unit area, wetlands have the largest soil carbon stocks in the world (WBGU, 1998).

The share of tropical wetlands in global wetland area is estimated between 30 per cent and 50 per cent if rice-growing areas are included. Excluding rice farmland, the proportion of tropical wetlands ranges between 10 per cent and 30 per cent. Despite their small share in total wetland area, the carbon stocks of tropical wetlands are of a magnitude similar to those of wetlands of the Northern Hemisphere. This is because their stocks per unit area are several times larger, both in the biomass and the soil compartment. The carbon stocks of tropical wetlands are seriously endangered, especially by land-use changes to rice cultivation (WBGU, 1998).

c) Mechanism of Carbon Storage in Wetlands

As in Ramsar (1997) Wetland ecosystems have unique characteristics as they are the sources of cultural, economic and biological diversity. These unique characteristics affect carbon dynamics and there are few mechanisms that aid in carbon storage in wetland ecosystem. In mechanism photosynthesis, wetland trees and other plants convert atmospheric carbon dioxide into biomass. Hence carbon may be temporarily stored in wetland trees and plants and the living material which feed upon them, and detritus including fallen plants and animals which feed upon them. Many wetland plants are known to use atmospheric carbon dioxide for their main C source, and their death/decay and ultimate settlement at a wetland bottom can have profound effect on C sequestration. Even this mechanism of storage through photosynthesis depends along the latitudinal gradient as growth of vegetation is slow for high latitude wetlands with less sun, nutrient and colder temperature (Shalu et al, 2009; Roulet, 2000).

Secondly, carbon rich sediment are trapped and stored that are brought along floods, hurricanes or even drained from watershed sources. However, long term storage is often limited due to rapid decomposition processes and rerelease of C to the atmosphere such as in case of paddy fields. Hence, wetlands are dynamic ecosystem where significant quantities of C from both wetland and non-wetland sources may also be trapped and stored in wetland sediments (Shalu et al, 2009;http://www.unep.or.jp/ietc,)

The balance between carbon input (organic matter production) and output (decomposition etc.) and the resulting storage of carbon in wetlands depend on several factors such as the topography and the geological position of wetland; the hydrological regime; the type of plant present; the temperature and moisture of the soil; pH and the morphology. Thus clearly carbon accumulation in wetlands is a complicated process influenced by many factors (Yarrow, 2009). There is a strong relation between climate and soil carbon pools where organic carbon content decreases with increasing temperatures, because decomposition rates doubles with every 10^{o}c increase in temperature (Schlensinger 1997).Tropical wetlands store 80% more carbon than temperate wetlands (Bernal, 2008).

d) Wetlands Role in Climate Change Adaptation and Mitigation

Wetlands play an important role in the regulation of global climate basically in two ways:

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through mitigation and adaptation. Their role in climate change mitigation is in two critical ways; management of GHGs and physically buffering climate change impacts. They act as significant carbon sinks and their restoration and creation will serve as carbon store/sinks and increase sequestration of $C0_2$ (MUNDITAS, 2008).

Mitigation, through reducing GHG emissions, largely concerns the protection and promotion of carbon sinks, through land-use and habitat management and also involves the encouragement of the use of non-carbon or carbon-neutral energy sources, and the improvement of energy efficiency (Berry et al., 2009).

IPCC (2002) defined mitigation as an anthropogenic intervention to reduce net greenhouse gas emissions that would lessen the pressure on natural and human systems from climate change. Mitigation options include the reduction of greenhouse gas emissions through the reduction of fossil-fuel use, reductions of land-based emissions via conservation of existing large pools in ecosystems, and/or the increase in the rate of carbon uptake by ecosystems.

Wetland ecosystems (including peatlands) also represent important natural carbon stores, and their restoration must be an essential component in climate change mitigation strategies. A recent report documents that carbon emissions from disturbed peatlands are equivalent to almost 8% of global emissions from fossil fuel burning. This is the most concentrated source of land-use related carbon emissions, produced on only 0.2% of the earth's land area. Based on these findings, the IPCC has subsequently concluded that the "restoration of drained and degraded peatlands is one of the key low-cost greenhouse gases mitigation strategies." Due to the rapid rate of vegetative growth and improved hydrology, wetland restoration is perhaps the most efficient (low-cost) method for sequestering carbon and reducing emissions in the short term (Bernal, 2008).

In terms of adaptation, wetlands and other well-functioning coastal ecosystems (i.e. dunes, mangroves and coral reefs) provide a critical bioshield against rising sea levels, the increased frequency and intensity of storms as well as fluctuating sea surface temperatures that result from climate change (SER,2007;I PCC, 2007).The world's biodiversity is adapting to climate change at large. However, there are limits to adaptation in natural ecosystems, small changes in climate may be disruptive and, beyond certain thresholds, natural systems may be unable to adapt at all (Dawson et al., 2008). Adaptation principles include promoting activities to reduce direct and indirect impacts, increase resilience and accommodate change. Measures that support these principles include: direct management; promoting dispersal of species; increasing available habitat, promoting ecosystem functioning; optimizing sectoral responses, and continuing to reduce pressures not linked to climate change.

SCBD (2009) defined ecosystem-based adaptation as the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change. Ecosystem-based adaptation uses the range of opportunities for the sustainable management, conservation, and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change. It aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change.

IV. Ethiopian Wetlands and Climate Change

Ethiopia, with its different geological formations and climatic conditions, is endowed with considerable water resources and wetland ecosystems, including twelve river basins, eight major lakes, many swamps, floodplains and man-made reservoirs. With the exception of coastal and marine-related wetlands and extensive swamp-forest complexes, all forms of wetlands are represented in Ethiopia. These include alpine formations, riverine, lacustrine, palustrine and floodplain wetlands (EFAP, 1989). Hillman and Abebe (1993) estimate that wetlands cover 1.14% of the total landmass of the country, while forests cover approximately 2%.

According to NMA (2007) and Nigist (2009), developing countries in general and least developed countries like Ethiopia in particular are more vulnerable to the adverse impacts of climate variability and change. This is due to their low adaptive capacity and high sensitivity of their socio-economic systems to climate variability and change. Current climate variability is already imposing a significant challenge to Ethiopia by affecting food security, water and energy supply, poverty reduction and sustainable development efforts, as well as by causing natural resource degradation and natural disasters.

The concept of vulnerability is a very complex one. Causes for vulnerability of Ethiopia to climate variability and change include very high dependence on rain fed agriculture which is very sensitive to climate variability and change, under-development of water resources, low health service coverage, high population growth rate, low economic development level, low adaptive capacity, inadequate road infrastructure in drought prone areas, weak institutions, lack of awareness, etc (NMA, 2007).

Climate related hazards in Ethiopia include drought, floods, heavy rains, strong winds, frost, heat waves (high temperatures), lightning; etc.Ethiopia has twelve major river basins, including the Blue Nile. Its

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riparian systems, combined with its eleven major lakes, make Ethiopia the "water tower" of Northeast Africa. Climate change is projected to cause a drying of wetlands (affecting threatened bird species breeding sites). Although, Ethiopia has relatively abundant water, it has one of the lowest reservoir storage capacities in the world: 50 cubic meters per person compared with 4,700 in Australia (World Bank, 2008).

V. Summary and Conclusion

Wetlands are among the world's most important assets, providing the basis for human survival and development, and contribute to global biodiversity. Among their significant functions, they reduce the greenhouse effect (through their capacity for sequestrating and retaining carbon); stabilize microclimates; provide tourism/recreation and water transport opportunities; retain and purify agrochemicals, toxicants and sediments; minimize natural disasters such as drought and floods; recharge ground water; and contribute to the hydrological characteristics of aquatic ecosystems. They also generate various products such as water supply, fisheries, wildlife, forest and agricultural resources. This all explicitly show the significance of protecting the wetlands ecosystems for climate change adaptation, biodiversity conservation and combating desertification and mitigate the effects of drought.

Wetland ecosystems, their biodiversity and the services on which humans depend, are threatened by the likely impacts of climate change inspite of their importance for climate change mitigation and adaptation.

Wetlands may affect the atmospheric carbon cycle in four ways. Firstly, many wetlands especially boreal and tropical peatl ands have highly variable carbon and these wetlands may release carbon if water level is lowered or management practices results in oxidation of soils. Secondly, the entrance of $C0_2$ into a wetland system is via photosynthesis by wetland plants giving it the ability to alter its concentration in the atmosphere by sequestrating this carbon in the soil. Thirdly, wetlands are prone to trap carbon rich sediments from watershed sources and may also release dissolved carbon into adjacent ecosystem. This in turn affects both sequestration and emission rates of carbon. Lastly, wetlands are also known to contribute in the release of methane to the atmosphere even in the absence of climate change (Shalu et al, 2009).

Degradation of wetlands and disturbance of their anaerobic environment lead to a higher rate of decomposition of the large amount of carbon stored in them and thus release GHGs to the atmosphere. Therefore, protecting wetlands is a practical way of retaining the existing carbon reserves and thus avoiding emission of carbon dioxide and other GHGs. Wetland biodiversity, ecosystems and species are indeed under threat from the impacts of climate change, but proper management of wetlands can reduce these impacts. It is urgent that the international community recognizes the crucial importance of wetlands to mitigate climate change (through reducing Greenhouse Gases). Equally, adaptation measures for wetlands (which deal with the impacts of climate change) are critically important to human welfare. From words to actions: policies, planning and implementation related to climate change, at all levels from global to local, should recognize and incorporate the role and importance of wetland ecosystems.

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