Impacts and Adaptations to Climate Variability and Change in Inland Riparian and Aquatic Ecosystems and Fisheries: A Review of Scientific Literature

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Equipping Small Scale Fishers and Riparian Communities with Adaptation Strategies to Cope with Impacts of Climate Variability and Change

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Summary
Aquatic ecosystems are important sources of fish and water which in African countries like Uganda contribute to national and agricultural GDP, employment, animal food protein, and export earnings while riparian ecosystems are important farming and grazing grounds. These resources are under increasing threat from impacts of climate variability and change but management has concentrated on threats of over-exploitation, invasive species, habitat change, and pollution. In this report, we review published and new data on impacts of climate variability and change on inland aquatic ecosystems, productivity and livelihoods against the assumption that changes in climate parameters such as temperature and rainfall affects physico-chemical conditions, primary productivity, fisheries and fishery yield and life history parameters of fishes. All these changes ultimately have consequences on livelihoods of people who depend on aquatic resources. We also review the possible adaptation strategies and applicable policies that aim at addressing impacts of climate variability and change. Available literature suggests that climate variability and change disrupts established seasonal climate patterns through increasing water temperature, unpredictable precipitation, wind stress, and influences physico-chemical factors such as light, nutrients, and dissolved oxygen that drive production processes of phytoplankton, invertebrate production and fish. These changes consequently affect the livelihoods of the people who depend on fisheries and other aquatic ecosystem services. In response fishers adapt to the changes either by intensifying fishing operations or diversifying fisheries livelihoods. Evidence is still scanty and there is need for more research to show how changing climate will affect aquatic ecosystem, fisheries and livelihoods. Effort should therefore be made to develop capacity, develop and share knowledge to increase awareness and take action to address impacts of climate variability and change on inland aquatic and riparian ecosystems and livelihoods.

Key words: Climate parameters, productivity, life history parameters, livelihoods, adaptation

1. Introduction

Fish has very high nutritional value contributing >20% of average *per capita* animal protein intake for more than 1.5 billion people worldwide (Cochrane *et al*., 2009) and are important for food, employment, income and export earnings. Some countries have large expanses of water for instance Uganda has five major lakes, 160+ minor lakes and a network of rivers and wetlands occupying about 21% of the area of the country which are important sources of fish. These aquatic systems, cover about 80,000 km^2, hold about 3,000 km^3 of water, produce about 1.5 million tons of fish annually (NFP 2004), are sources of water for agriculture, domestic and industrial use, are important in navigation and modulate local climate. Fish contributes 3% to national GDP and 13% to agricultural GDP, employs up 1.2 million people, provides over 50% of animal protein food, contains omega-3 fatty acids which have health benefits, and is the most important non-traditional export commodity in Uganda. Also, the highest human and livestock population live in proximity of aquatic systems using them for crop agriculture and grazing of animals and communities are expected to increasingly move towards aquatic systems to get access to water as climate variability and change makes water scarce or gets relocated when displaced by floods.

Greenhouse gases mainly carbon dioxide, methane and nitrous oxide emitted from combustion processes have accumulated in the Earth’s atmosphere and are trapping heat causing global warming. According to the United Nations Intergovernmental Panel on Climate Change (IPCC, 2007), the last two decades of 20th century were the warmest in 400 years. This warming is causing an upsurge of extreme weather events, strong hurricanes, drought, floods, and other natural disasters. Some deserts have expanded and some inland waters shrunk or even dried up causing water and food shortages and affecting aquatic organisms and riparian communities. Species have become extinct due to disappearing habitats and changing ecosystems (Jeppesen *et al.*, 2010). Human therefore needs to understand what is happening and take action.

Climate variability and change contributes to poverty, water and food insecurity, poor sanitation, disease epidemics and infrastructure damage. Africa is among the most vulnerable continents due to its high poverty levels and dependence on climate sensitive natural resources comprising of crops, forestry, livestock and fisheries (IPCC, 2007). About 40% of the GDP of most countries of Sub-Saharan Africa come from natural resources and about 80% of them depend on agriculture and natural resources which are sensitive to climate variability and change for their livelihood. Unfortunately, about 240 million people in Africa are poor and food insecure (FAO, 2010a) and this reduced their capacity to adapt to disasters such as those that might come from climate variability and change. Unless action is taken to curtail impacts of climate change, Africa is not likely the meet the MDG which aims at reducing poverty and hunger.

International, regional and national policy and legal documents such as the United Nations Framework Convention on Climate Change UNFCCC (United Nations, 1992) and its Kyoto Protocol, The East African Community Climate Change Policy (EAC, 2011), the Uganda National Development Plan 2010-2015, and the National Agricultural Development Strategy and Investment Plan (DSIP) 2010-2015 have recognized that African countries like Uganda among the most vulnerable and least climate resilient and prioritized improved knowledge, policy, legislation and governance systems, and increased awareness of climate change issues at all levels. However, effort to address climate change have tended to concentrate on crops, forestry and livestock and less on fisheries despite the high contribution of fisheries to poverty reduction, food security, employment and export earnings all over the world. National Adaptation Programmes of Action (NAPA) for many countries have also not prioritized fisheries as one of the key areas that need intervention in relation to climate change (FAO, 2011; Republic of Uganda, 2007). Fisheries research and training in inland waters of Africa including Uganda have also not previously addressed impacts of climate variability and change on aquatic resources. Most of the emphasis in management of fisheries and aquatic resources has concentrated on threats due to over-exploitation, invasive species, habitat change and pollution. As a results, there is limited capacity, knowledge, policies and regulations, and awareness on how inland aquatic ecosystems, productivity, fisheries resources, and fishers are affected by climate variability and change, and how they can adapt and cope with impacts of climate variability and change on their livelihoods. There is therefore need to improve capacity and knowledge systems, provide policy and regulatory framework and increase awareness and take action to address climate variability and change on inland fisheries and the livelihoods of depended communities. Here, we review literature on impacts of climate variability and change on aquatic ecosystems, productivity, fisheries and livelihoods. We assume that changes in climate parameters such as temperature and rainfall will affect physico-chemical conditions, primary productivity, life history parameters of fishes and fishery yield. These changes will ultimately have cascading effects on livelihoods of people who depend on fisheries and other aquatic resources and they will need to adapt to sustain their livelihoods. This will require appropriate policies and action.

2. Progression in key threats to aquatic resources and productivity

The key threats to natural resources including aquatic resources and fisheries have been categorized as over-exploitation, invasive species, habitat change and pollution (Loh, 2008). These have progressively become important with human civilization and increases in human and livestock population (Hecky, 2010). For instance, from early to mid-20th century fish catches from Ugandan lakes comprised 12 to 15 species and many of the lakes had over 500 species which although not commercially exploited contributed to stability of their respective ecosystems. By the beginning of the 21st century the number of exploited species had decreased to between three and five species. Total annual fishery yield from Uganda initially decreased to about 60,000 at the beginning of 1960s (**Figure 1**). This initial decline was attributed to over-exploitation. Nile perch (*Lates niloticus* L.) and three tilapia species including the Nile tilapia (*Oreochromis niloticus* were then introduced into lakes Victoria and Kyoga to boost production. The introduced species got established and initially contributed to increases in catches to 220,000 t in 1978 following establishment of introduced Nile perch and Nile tilapia in Lake Kyoga. Kyoga catches had started to decrease in 1980s again largely due to over-fishing and habitat changes but the overall impact on national fisheries yield was offset by a rise in catches in Lake Victoria after 1980s following establishment of the same introduced species which resulted in an increase in annual national fishery yield to 245,000 t in 1990. The catches in Lake Victoria started to decline again and although this was still largely attributed to over-exploitation, habitat degradation and pollution started to manifest about this time and contributed to the changes in the fish habitat and fisheries. It also coincided with the time when climate change were starting to manifest (Hastenrath & Kruss; 1992; Kolding *et al*., 2008; Hecky *et al*., 2010; Sitoti *et al*., 2010). This is likely to have started contributing to changes in physico-chemical conditions, productivity processes and fisheries in Lake Victoria and other African Great Lakes regions from about the 1970s but its role has not be examined.

The Intergovernmental Panel on Climate Change (IPCC, 2007) reported that the last 20 years were the warmest in the 20th century and the Uganda Meteorological Department (GoU, 2007) also reported that the frequency of droughts increased in the last part of the 20th century (**Figure 2**) and analysis of available suggests that temperatures in Uganda increased by about 1^{o}C over the past 50 years (Mubiru *et al*., 2009). Aquatic productivity processes and fish stocks in Ugandan lakes also started changing considerably during this period with small pelagic fishes increasing rapidly especially in lakes Victoria and Albert over the last two decades of the 20th century and the beginning of the 21st century. It is important to start examining how climate change relates to changes that were recorded in physico-chemical conditions, aquatic and fishery productivity processes especially after the 1970s.

3. Vulnerability of aquatic systems

Freshwater ecosystems and organisms are believed to be susceptible to climate variability and change (Barenge & Perry, 2009). Shallow aquatic systems are thought to be affected mainly through flooding and desiccation while in deep ones, effects on water circulation is likely to be important. Paleo records show that shapes and distribution of lakes have changed and some have even disappeared due to extreme climate events. For instance, among the Ugandan lakes, the surface of Lake George desiccated (Haworth, 1977), Lake Edward has had several low water stands over the past 5000 years (Russell & Johnson, 2005), Lake Albert was greatly reduced in history (Beuning *et* *al*., 1997) and Lake Victoria was desiccated as recently as 12,000 years BP (Johnson *et al*., 1996). These changes have been attributed to natural warming and cooling cycles which occur over hundreds to thousands of years but they provide an indication on what is likely to happen when extreme changes in climate parameters especially temperature occur. For instance, the area of Lake Chad has shrunk to about 5% its original size due to dry climate (Barenge & Perry, 2009). These changes in lakes ecosystems molded These changes in aquatic systems affect organism that inhabit them and the livelihoods of communities the evolution which resulted the species of fishes and other organisms that inhabit these lakes. Lakes are also like islands with many of them enclosed by land masses. Climate change will cause either shrinkage of the lakes as in the case of Lake Chad or expansion of these lakes due to flood events and internal dynamics of the lakes will be affected through effects of climate change on water circulation with consequences on organisms in them and the people who depend on them. There have, however been limited attempts to relate change in climate to lake and fishery productivity processes. This has become more urgent with climate change as this is expected to affect morphometry, physico-chemical conditions, productivity processes, fisheries and consequently the livelihoods. This review brings together some literature that has indications of impacts of climate variability and change on inland riparian and aquatic ecosystems, organisms and livelihoods.

4. Manifestations of climate change in aquatic systems

Information that global climate seems to be affecting riparian ecosystems, aquatic habitats, lake productivity processes, life history of fishes and fishery yield has started to accumulate (Barenge & Perry, 2009). The impacts are associated with changes in climate parameters especially temperature and precipitation. These seem to affect physico-chemical conditions, productivity processes, food-webs, physiology, composition, distribution and abundance, community structure, phenology, regime shift of fishes and other aquatic organisms. They may however not act independently but may interact with non-climatic factors such as exploitation, invasive species, habitat change, and pollution to affect aquatic ecosystems and organisms (Schindler, 2001).

4.1. Temperature

Africa became warmer by 0.5^{o}C over the 20th century and the rate of warming is accelerating - it was 0.2^{o}C per decade at the end of the 20th century compared to about 0.05^{o}C at the beginning of the century (Hulme *et al*., 2001). The temperature of the deep African Great lakes including Kivu (Lorke *et al.*, 2004), Tanganyika (Verburg *et al.*, 2003; Verburg and Hecky, 2009; Tierney *et al.*, 2010), Malawi (Vollmer *et al.*, 2005), Victoria (Hastenrath & Kruss 1992; Hecky *et al.*, 2010), Albert (Stuart Heather-Clark & Albert de Jong, 2007) and Edward (WWF, 2006) have risen by about 0.2^{o}C to 0.7^{o}C since the early 1900. Warming is accompanied by increases in the frequency of extreme weather events such as heavy rains, storms, hurricanes, flooding and drought. Rising temperatures affect heat budget, evaporation, water balance, stratification, mixing of nutrients and oxygen and aquatic productivity processes in aquatic systems. Temperature affects metabolism and physiology of aquatic organisms since many of them especially fishes are cold blooded. Warming enhances stratification and anoxia which can change phytoplankton composition and their timing and cause mismatch between prey (phytoplankton and zooplankton) and their fish predators which affects production, biodiversity, fishery yield, spawning migrations and timing of peak abundance of some aquatic organisms.

4.2. Precipitation

Fluctuations in precipitation are manifested in quantity of rainfall, floods and drought. Flood events can increase productivity as nutrients are washed into aquatic systems but may also enhance siltation, displace communities and destroy infrastructure. A drop in water level may affect breeding and nursery areas for some fishes and production of near-shore fishes and their prey organisms while increase in floods increases fish yield due to expansion of feeding and breeding areas as was the case with tilapia species after the exceptionally high El Nino rains of the early 1960s (Welcome, 1970). Reduction in precipitation reduces water levels and increased drought which affects productivity of onshore fisheries and associated organisms and increases vulnerability of riparian communities. Increased precipitation and floods damages productive assets - ponds, rice field and homes, displaces populations and increases human vulnerability. Less predictable rains decrease the ability to plan farming activities and increase vulnerability of riparian communities. Increased run off and flooding boosts algal abundance and productivity in shallow near-shore areas and may change the dominant algal types with consequences on the food-web. An impression of possible impacts of flooding due to climate variability on aquatic systems can be obtained from changes that took place following *El-Nino* events such as those which occurred in East Africa in 1961-1964 and 1997-1998. Heavy rains during these periods caused drastic increases in lake levels in 1961-1964 and 1997-1998 (**Figure 3**), displaced riparian communities and caused economic losses.

4.3. Wind stress

Wind speed and direction interact with thermal structure, water transparence and incident radiant energy to set the critical mixing depths for growth of different algae and zooplankton. Increased up-welling may increase phytoplankton biomass and production. Wind power is responsible for upwelling, internal and surface waves and water circulation. Wind stress can bring anoxic waters to the surface and result in fish kills or algal blooms. Timing of upwelling may **c**hange distribution especially of pelagic fishes and their prey organisms. Distribution and intensity of storms increases risks associated with fishing, damages coastal infrastructure, aquaculture installations such as cages and ponds and displaces human populations (Daw *et al*., 2009).

4.4. Solar radiation

Solar radiation affects heat budgets and in combination with water transparency controls the vertical extent of photosynthesis and visually dependent predator-prey interactions. Light affects biomass of phytoplankton and their species composition.

5. Impacts on riparian and aquatic ecosystems

5.1. Coastal areas, riparian infrastructure and settlements

Coastal and riparian ecosystems are affected though flooding and desiccation and these can, affect the aquatic ecosystem, productivity and livelihoods, cause infrastructure damage and displace communities. Fluctuations in water levels impact wetlands, fisheries, and other human activities. For instance, heavy El-Nino rains of 1997/98 dislodged aquatic macrophytes which blocked the outlet of the Nile to Lake Kyoga, caused flooding, and displaced communities (ILM, 2004). Floods can also cause landslides and coastal erosion while drought can results in receding of water levels resulting in encroachment on aquatic habitats.

5.2. Wetlands and shallow aquatic habitats

Wetlands are important habitats as spawning and nursery grounds for both marine and freshwater fishes. Wetlands protect inland aquatic systems from siltation and reduce pollutants to aquatic systems. Wetlands retain water and release it slowly and play an important role in regulating floods, trap silt, retain water and release it slowly and provide refugia for fish and other organisms (Chapman *et al.,* 2001). Rising temperatures and unpredictable rainfall are likely to affect wetland coverage with consequences on aquatic health and productivity. Climate change can either result in floods or drought which can results on encroachment on wetlands. For instance in Uganda. Wetlands have been encroached upon especially as water recedes due to climate factors. For instance 48.5% of wetlands in the Kyoga region were lost between 1994 and 2008 alone due to conversion to agriculture (Ministry of Water and Environment, 2010). It is important to protect wetlands along aquatic systems. Forest cover plays a key role in reducing erosion along riparian ecosystems. It can also serve as a carbon sink and assist in mitigation of climate change. There will be need to promote reforestation and a forestation using appropriate tree species along riparian ecosystems.

5.3. Shallow aquatic systems

Shallow lakes such as Chad, Chilwa, Kyoga and Wamala and shallow inshores areas of rivers and deep lakes are particularly vulnerable to climate variability and change. The area of Lake Chad has dropped to about 5% its original size due to climate and other factors **(Figure. 4)**. The area of Lake Chilwa has dropped several times due to drought (Allison & Oliver 2007; O'Reilly *et al*., 2003). The area of Lake Wamala has fluctuated between 100-180 km^2 and the average depth changed between 1.7 m and 4 m.

5.4. Deep lakes

The abnormally high *El-Nino* rains around 1961 increased lake levels flooding inshore areas of Lake Victoria (Welcomme, 1970). The drought of 2004 contributed to a fall in water level of Lake Victoria by 1.64 m.

6. Impacts on aquatic productivity processes

The changes in aquatic and fishery productivity that follow changes in physico-chemical condition some insight in what should be expected as climate change intensifies. Change in fish community structure leading to increased proportions of smaller-bodied individuals (Jepssen *et al.,* 2010 and Murisa Ndebere *et al* 2011) associated with climate warming is expected to impact other lake processes, such as nutrient dynamics and mobilisation. In general, communities characterized by small species have higher population densities than communities with larger species (Lawton, 1991). Based on allometric laws, the excretion rates of individuals increase with decreasing body biomass and, therefore, communities with the same total biomass but dominated by small fish are thought to have higher metabolic and excretion rates (Vanni, 2002) than communities dominated by larger fish, factors that contribute to faster recycling and greater movement of nutrients within the system thereby predisposing the lake eutrophication; a secondary impact of climate warming. Productivity processes especially in deep lakes are affected through changes stratification, nutrient circulation and enhancement of anoxia (oxygen deficiency). Aquatic productivity processes are affected through changes in phytoplankton composition and primary production, invertebrate composition and production, and food-webs.

6.1. Physico-chemical conditions

Climate warming through its effects energy balance could be contributing to changes in circulation dynamics, physico-chemical and production processes, increases in stratification, reduction in mixing, upwelling and recycling of nutrients, and enhancement of anoxia in lakes Tanganyiga, Malawi, Kivu and Victoria and Albert (Lehman *et al*., 1998; Hecky *et al*., 1994, 2010; Verburg, Hecky & Kling, 2003; Hecky, Bootsma & Odada, 2006; Barenge & Perry 2009,). Lake Albert is becoming warmer with more persistent stratification and more anoxic bottom waters apparently as a response to climate change (Stuart Heather-Clark & Albert de Jong, 2007). Changes in composition, diversity, distribution and production of certain aquatic organisms including fish are expected as global warming intensifies. Climate warming enhances increases vertical stratification which affects vertical mixing of nutrients and decreases productivity, and hypoxia especially of deep lakes and the stratified period may be lengthened due to increased warming.

6.2. Phytoplankton production and composition

Primary production could decline due to increased stratification and decreased nutrient supply. Decreasing primary production will change phytoplankton composition to smaller forms. Increased vertical stratification and water column stability will reduce nutrient availability to the euphotic zone and affect primary. This will impact community composition, production processes of phytoplankton. A decrease in primary production in Lake Tanganyika by up to 20% over the past 200 years has partly been attributed to climate warming and this is thought to have affected fishery production (**Figure 5)** (O'Reilly *et al.*, 2003).

6.3. Invertebrate production and composition

The abundance of zooplankton population depends on its phytoplankton prey. Climate change is likely to affect the structure of the zooplankton community. Disruption of the thermocline due to climatic factors is thought to have collapsed the zooplankton community in the North Atlantic to less than half their original biomass (Barange & Perry, 2009). Studies of the Danish lakes suggest that there was a decrease in the average size of cladocerans and copepods with increasing temperature (Gyllstrom *et al*., 2005) together with a higher proportion of small individuals within the fish communities. This is in agreement to the tendency of decreased zooplankton:phytoplankton biomass ratio, and a reduced proportion of Daphnia amongst the cladocerans with increasing temperature (Jeppesen *et al*., 2009).

6.4. Food-webs

Climate change through its effect on ecosystems and their species is expected to disrupt food webs, timing, match or mismatch between when food is available and their juvenile stages and will affect recruitment and subsequent abundance of the fish. If the lakes have higher chances of becoming more eutrophic as is the case for most small shallow lakes, the consequent shift in fish community structure towards high abundance of small fish as indicated by Jeppesen *et al* (2010) and Murisa Ndebere *et al* (2011) may further enhance the predation pressure on zooplankton (Jeppesen *et al*., 1994). Moreover, large-bodied cladocerans may diminish or disappear first followed by other cladocerans depending on nutrient enrichment (Jeppesen *et al*., 2007; Brucet *et al*., 2009; Jensen *et al*., 2010). This may reduce grazing on phytoplankton and enhance further eutrophication (Jeppesen *et al*., 2007). In addition, the higher degree of omnivory of the fish in warmer lakes implies that their populations can be maintained by alternative food sources when the zooplankton population is diminished. Consequently, the predator–prey dynamics may be uncoupled (Lazzaro, 1997), allowing an even higher predation pressure on zooplankton and macro-invertebrates. Match or mismatch of predator and prey are important in recruitment and subsequent yield.

7. Impacts on composition, distribution, abundance, fishery yield and life history of fishes

Changes in primary and secondary productivity associated with changes in physico-chemical conditions arising from changes in temperature and precipitation are expected to affect life histories, physiology, composition and diversity, distribution, population structure, growth, phenology (timing of life history events), regime shift, life history characteristics of fishes (food, population structure, size at maturity etc) of fishes and fish stocks.

7.1. Composition, diversity, distribution, abundance and population structure

Climate factors modify biological cycles of fish which are adapted to certain hydrological conditions especially seasonal patterns such as in riverine species. For example, rising temperatures have both direct and indirect effects on fish production where, the spatial distribution of fish stocks might change due to the migration of fishes from one region to another in search of favorable conditions (Mohanty *et al*., 2010). Increased discharge rates through prolonged floods are thought to have boosted fish yield in Mekong river (Barenge & Perry, 2009). Climate change is therefore expected to displace fish species to those that are tolerant of the changed conditions. More tolerant taxa such as Clariidae (e.g. *Clarias gariepinus*), Lepidosirenidae (e.g. *Protopterus eathiopicus*) which are tolerant to low oxygen conditions are expected to persist as oxygen deficiency in aquatic systems increases with temperature while the less tolerant taxa may disappear (Lae, 2001). Also fishes like *Oreochromis niloticus* which are able to adjust their life history characteristics may have higher chances of survival. Invasive species and those with high fertility rates and dispersal capabilities have been shown to be highly adaptive to variable climate conditions (Malcom *et al*., 2002) and these may flourish with changing climate. Declines in fish abundance in some East African Rift Valley lakes have been linked to climate impacts on the ecosystem whereby the pelagic fishery were consistent with a lake-wide shift in ecosystem functioning (O'Reilly *et al*., 2003).

Climate change will modify distribution of freshwater species through shifts in distribution of plankton, invertebrates and fishes. Changes in timing, intensity and duration of floods will affect migration especially of riverine fish species and will affect spawning and transport of spawning products. Hall and Welcomme (2004) concluded that minimizing drawdown and maximizing floods increases fish production. Warming is expected to affect vertical movements especially of pelagic species.

7.2. Physiology

Fishes are cold-blooded organisms and their metabolic rates are strongly affected by warming. Increasing temperature affect physiology of fishes because of limited oxygen transport to tissues at higher temperatures. Temperature stress affects physiological processes such as oxygen demands and food requirements since oxygen is less soluble in water at higher temperatures. Temperature mediated physiological stress and timing may affect recruitment success, abundance and populations and changes in abundance and can alter composition and growth rate.

7.3. Timing of life history events

Changes in timing of floods may trigger production at the wrong time from plankton to invertebrates and fish. Shifts in species phenology including spring advancements and delays of annually recurring life cycle events are amongst the most severe consequences of global warming (Durant *et al*., 2007). These shifts are often unequal amongst species and trophic levels, causing a mismatch between the phenology of organisms and their food. By interrupting energy flows between trophic levels, warming is expected to complicates the prediction of ecosystem responses. Climate warming is therefore expected to disrupt fish species recruitment and alter fish community structure via mismatches between planktonic predators and prey. Yet, such effects are still poorly documented in lake systems (Straile *et al.*, 2007) and it is also likely that adaptation will eliminate mismatches in the long term.

7.4. Regime shift

Climate change may shift species dominance. It may provoke sudden and unpredictable responses as ecosystems shift from on state to another. Regime shifts in fish stocks have been observed to be mediated not only by over-fishing and pollution but also by climate change. Long-term changes in sea surface temperature in the North Atlantic have been associated with changes composition of zooplankton and recruitment especially of small pelagic fishes (Barenge & Perry, 2009). In the Congo, *Sardinella maderensis* dominated the catch when temperature was moderate to cool while *S. aurita* became the most important species after pronounced warming (Binet, Goberta & Maloeukib, 2001). In the Gulf of Guinea, seasonally-induced plankton production due to climate variations was associated with increases in catches of *Sardinella aurita* (Binet & Servin, 1993). Similarly climate warming may be contributing to the sudden increases in pelagic cyprinid species (*Neobola bredoi*, and *Brycinus nurse*) in Lake Albert and *Rastrineobola argentea* in Lake Victoria and this need scrutiny in relation to climate factors.

7.5. Life history characteristics

There is close relationship between life history parameters and temperature. Cool water species are more affected by slight temperature change than warm water fish (Parmesan, 2006). A cross-comparison of fish populations in temperate lakes has shown that lower-latitude fish species are often not only smaller, but also grow faster, mature earlier, have shorter life spans and allocate less energy (as gonadosomatic index) to reproduction than populations at higher latitudes (Blanck & Lammouroux, 2007). For example, in a reservoir in northeastern France exposed to heated waters (3–5^{o}C over control temperature), a population of pumpkinseed (*Lepomis gibbosus*) displayed faster growth of young of the year fish, precocious maturity and a shorter life span than usual and, consequently, higher mortality rates just after the first reproduction (Dembski et al., 2006). An analysis of Arctic charr populations from Lake Elliðavatn, SW Iceland has indicated lower longevity, lower age at maturity, lower maximum size and increasing growth rates with decreasing latitude (Malmquist, 2004). In a study conducted in 50 Swedish Lake averaging data for 14years, the mean size of Perch indicates a declining trend with altitude **(Figure 6)** emphasizing the importance of temperature on size structure of fish. In Lake Kariba, the mean weight of fish has continuously declined within the last half of the 20th century corresponding to an average increase in water temperature of 2°C **(Figure 7).** In Lake Wamala, where the lake has undergone fluctuations in water level, the size structure of the fish has been closely correlated to changes in lake level. Between 1975 and 1985 when the depth of the lake was about 4 m Nile tilapia (*Oreochromis nilotucus* L.)

grew to 40 cm and matured at 25 cm (Okaranon 1993). When the water level dropped to about 1.5 m, the fish grew to a maximum size of 23 cm and matured at 15 cm but when the water level rose again in 1997-1998, the life history parameters of the fish reverted to the pre 1985 values (NaFIRRI unpublished).

8. Impacts on fishery production and yield

The effects on fishery production is expected to include changes in the composition, relative abundance, and biomass of the fishes available for harvesting. This will influence the types and sizes of gears and methods used to exploit the fisheries. Warming of the lakes is expected to cause changes in distribution and production of certain aquatic organisms (IPCC, 2007) and to shift fisheries to smaller, faster growing, opportunistic species that can adapt quickly to the changed environment (FAO, 2010b). In Lake Elliðavatn, a more temperate Lake in South West Iceland, the Catch per unit effort of Arctic charr has continuously decreased over the last three decades corresponding to a rise in water temperature **(Figure 8)**. In the shallow highly productive Lake Chilwa in Malawi which has undergone periodic drying, fishery yield has been highly related to rainfall variations of the lake (**Figure 9**). Time series data for Lake Chilwa shows that fishery productivity is highly correlated with precipitation (Allison *et al.*, 2007). Expansion of inshore areas in lakes Victoria and Kyoga during the exceptionally high El-Nino rains is thought to have expanded breeding and nursery areas and caused a boom in the tilapia fishery in the mid-1960s (Welcomme, 1970). In Lake Wamala, another shallow lake in Uganda, the fishery yield reached its peak following establishment of introduced tilapias in early 1970s (Okaranon, 1993). The yield drastically declined from 7 tons to about 0.5tons following drought that lasted 6 years from 1980 and only slightly increased to 1.2t following a slight recovery of the lake level **(Figure 10)**.

In deep African great lakes, the importance of pelagic species such as *Rastrineoboa argentea* in lakes Victoria and Kyoga, *Brycinus nurse* and*Neobola bredoi* Poll) in Lake Albert have increased in importance to contribute 40% to 80% to fishery yield in lakes Victoria and Kyoga since the last two decades of the 20th century when climate change has become more intense. In West Africa, pelagic fisheries of *Sardinella aurita* increased in importance following pronounced warming (Binet, Goberta & Malouekib, 2001). Small pelagic fishes may be able to survive in an environment stressed by climate change because they can shift their habitat to the pelagic zone to avoid anoxic deep waters.

The above notes suggest that climate change seems to be affecting physico-chemical conditions, primary and secondary productivity and fishery yield. There is now need to closely examine the extent to which climate affects fisheries to inform management.

9. Livelihoods, impacts, adaptation and mitigation

9.1. Livelihoods

Africa is one of most vulnerable continents to climate change due to high dependence on climate sensitive natural resources such as crops, forestry, livestock, and fisheries. On average, 40% of the GDP of African countries is derived from agriculture and the sector employs about 80% of the population in Sub-Saharan Africa. Fisheries are important in food security, employment and export earnings. For instance, in Uganda, they contribute 3% to national GDP and 13% to agricultural

GDP, employs up 1.2 million people, and provide over 50% of animal protein food. It is also the most important non-traditional export commodity from Uganda.

9.2. Impacts on livelihoods

Climate warming and the associated unpredictable and changing precipitation, floods and drought and other variables such as wave action, wind velocity are expected to cause significant ecological and biological changes in the ecosystem and the resident fauna (Cheung *et al.,* 2009), and to impact on the people whose livelihoods depend on them. Extreme weather events may also impact fishing operations and land-based infrastructure (Westlund *et al.,* 2007). Fluctuations of fishery production and other aquatic resources can impact livelihoods of fishing communities (Iwakasi *et al.,* 2009; Sarch & Allison, 2000). Storms and severe weather events can damage infrastructure such as landing sites, boats and gear (Jallow *et al.,* 1999). For instance during Hurricane Gilbert in 1998, Jamaican fisher folk lost 90% of their traps resulting in a loss of revenue and high cost of repairs, as well as the ability to resume fishing activities promptly (Aiken *et al.,* 1992). Loss of fishing tackle and associated with the Hurricane was estimated at US$1.2million (Mitch, 1998). In Peru, during the *El Nino* of 1997–1998, rural fishing villages in the northern part of the country were damaged by heavy rains and were unable to transport their products to markets due to washed out roads and bridges (Broad *et al.,* 1999). Around Lake Kyoga in Uganda, *El Nino* rains of 1997/98 displaced communities, suspended fishing and caused heavy losses due damage of infrastructure. The economic loss due to such extreme events has not been fully quantified though.

9.3. Adaptations

Small-scale fisheries and riparian communities have responded to impacts of climate variability and change by changing fisheries operations, diversifying species targeted, intensifying fishing operations, abandoning fishing and taking on other livelihood occupations, migration to less affected areas, shifting to other forms of fisheries production such as aquaculture, exploiting both aquatic and terrestrial resources, diversifying income to other natural resources (such as crops, forestry and livestock), and resorting to social capital and community support. For example, during droughts periods on Lake Chilwa with remarkable decrease of fish catches (**Figure 9**), some fishers diversified their livelihoods to farming, pastoralism, and while others migrated to other lakes. In Peru, during *El Nino* event of 1997–1998, boats previously equipped with gillnets and purse seines were modified to utilize trawl nets to exploit the shrimp resource that emerged in the country (Broad *et al.,* 1999).

The National Adaptation Programmes of Action (NAPA) that are being targeted by the EAC Partner States related to aquatic and riparian ecosystems include: strengthening of meteorological services, efficient use of water, irrigation, protection of wetlands, coastal and forest ecosystems, improving land use management, climate proofing social infrastructure, and reducing climate sensitive vector and water borne diseases (EAC, 2011). However, these need to be guided.

9.4. Mitigations

The mitigation measures that have been identified at international, regional and national levels include: afforestation, reforestation, promotion of energy efficient systems, improvement of crop production systems, waste management, promoting Clean Development Mechanisms (CDM).

9.5. Gender considerations

Women, youths and men may be affected differentially by impacts of climate variability and change. There is need to consider vulnerability of the different groups when addressing climate issues.

10. Impacts on parasites and disease incidences in fish

Temperature is one of the key driving forces behind many ecological processes that affect the life-cycle of parasites (Chubb, 1980; 1982). Global increase in average temperatures is expected to affect productivity of capture fisheries and aquaculture systems by increasing the vulnerability of fish species to parasite attacks and diseases (Marcogliese, 2001). Climate change increases susceptibility of fish to disease as their immune function is compromised in the presence of stressors like high temperatures and crowding (Ficke *et al*., 2007). For example, whirling disease (*Myxobolus cerebralis*) impact on juvenile fish may become severe as temperatures increase (Schister *et al*.,1999). High temperatures and reduced oxygen concentrations are also expected to lead to proliferation of gill parasites, thus causing respiratory problems and even death of infected fish (Pojmanska *et al*., 1980). Climate changes is also expected to indirectly affect parasites and their hosts in aquatic systems through alteration in water levels, eutrophication and ultra violet radiation (Marcogliese, 2001; Cochrane *et al*., 2009). There is therefore need to explore effects climate change on infestation of fish parasites and diseases. In Lake Wamala, preliminary observations have shown that African catfish which is the emerging dominant fishery in the lake is heavily infested with parasites there have no efforts to relate this to changes in climate parameters.

11. Impact on aquatic weeds such as water hyacinth

Increased rainfall and hurricane intensity results in flooding events that facilitate the dispersal of aquatic weeds such as water hyacinth (Michener *et al.,* 1997). Water hyacinth can survive both extremes of climate change and can re-establish and colonize both in up and down stream systems and its colonization can be triggered by increased temperature (Center & Spencer, 1981). Extreme events may also create conditions which make ecosystems more exposed to invasion by aquatic weed such as water hyacinth. Changing climate is therefore expected to stimulate proliferation of certain aquatic weeds such as water hyacinth.

Knowledge systems to address climate change are still weak and less precise as indicated in the preceding sections. They is therefore need to create this knowledge system.

12. Policies, regulations and governance systems

There are international, regional and national policies and plans that can invoked to address impacts, adaptations and mitigation of climate variability and change. Those that apply to aquatic systems include those on environmental, wetland, fisheries, land use and coastal area management.

12.1 Policies

The regional policy that can be applied to address climate change issues include the East African Community (EAC) Climate Change Policy (EACCCP) (EAC, 2011). These policies have called for among other creating capacity, creating knowledge systems, development of adaptation and mitigation measures, introducing climate change in training programs, increasing awareness, and gender considerations.

12.2. Regulations

The international legal instruments that form the foundation of addressing climate issues include those of Environment and Development and the UNFCCC) and its Kyoto protocol. In East Africa, the regional (EAC) legal instruments that can be applied to address climate change issues include: The Protocol on Environment and Natural Resources; The Protocol for sustainable development of the Lake Victoria Basin. In Uganda, the national regulations include: The Constitution of the Republic of Uganda 1995, The Local Government Act of 1997, The National Environmental Statute, The Land Act of 1998, The Tree Planting Act and The Fisheries Act.

12.3. Governance systems

The United Nations is the main international organization responsible for climate change. It has a Secretariat to coordinate climate change issues. At regional level, the EAC has created a regional Climate Change Coordination Mechanism to address climate issues. At national level climate issues are coordinated by a Climate Change Unit located in the Ministry of Water and Environment and the NEMA. However, since climate change is an multi-sectoral issue, most of the sectors especially those responsible for aspects impacted by climate change require a component of climate change in their development plans.

12. Capacity building and gender considerations

Although climate change is a multi-sectoral issue, the capacity to address climate change in most sectors is weak or even non-existence. There have also not been targeted curricula and training programs in training institutions. International, regional and national policies have recommended incorporating climate change in training curricula of different disciplines and at different levels of training from primary to tertiary institutions.

14. Increasing awareness

Limited awareness has been singled out as one of the main constraints to addressing climate issues at international, regional and national levels. The international community is therefore targeting efforts to increase awareness. Many networks such as Climate Exchange network for Africa (CENA) and Africa Adapt have been created to spearhead sharing of information. There is however need to generate and package the information to be shared in appropriate packages.

15. Conclusions and recommendations

Climate variability and change is a major environmental and socio-economic problem which poses a major challenge to natural resources such as fisheries and livelihoods. The international, regional and national governments and institutions are increasingly recognising this challenge. There is need to understand the impacts of climate variability and change on different production sectors and on livelihoods. The capacity, knowledge, policies, regulations, awareness are all still weak and need to be built to maturity if the challenges posed by climate change are to be adequate addressed to reduce their effects on livelihoods. Policies to address climate change issues at international, regional and national levels have been developed and there are some international, regional and national legal instruments which can be applied to address climate issues but putting these in practice still remains a challenge.

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Figures

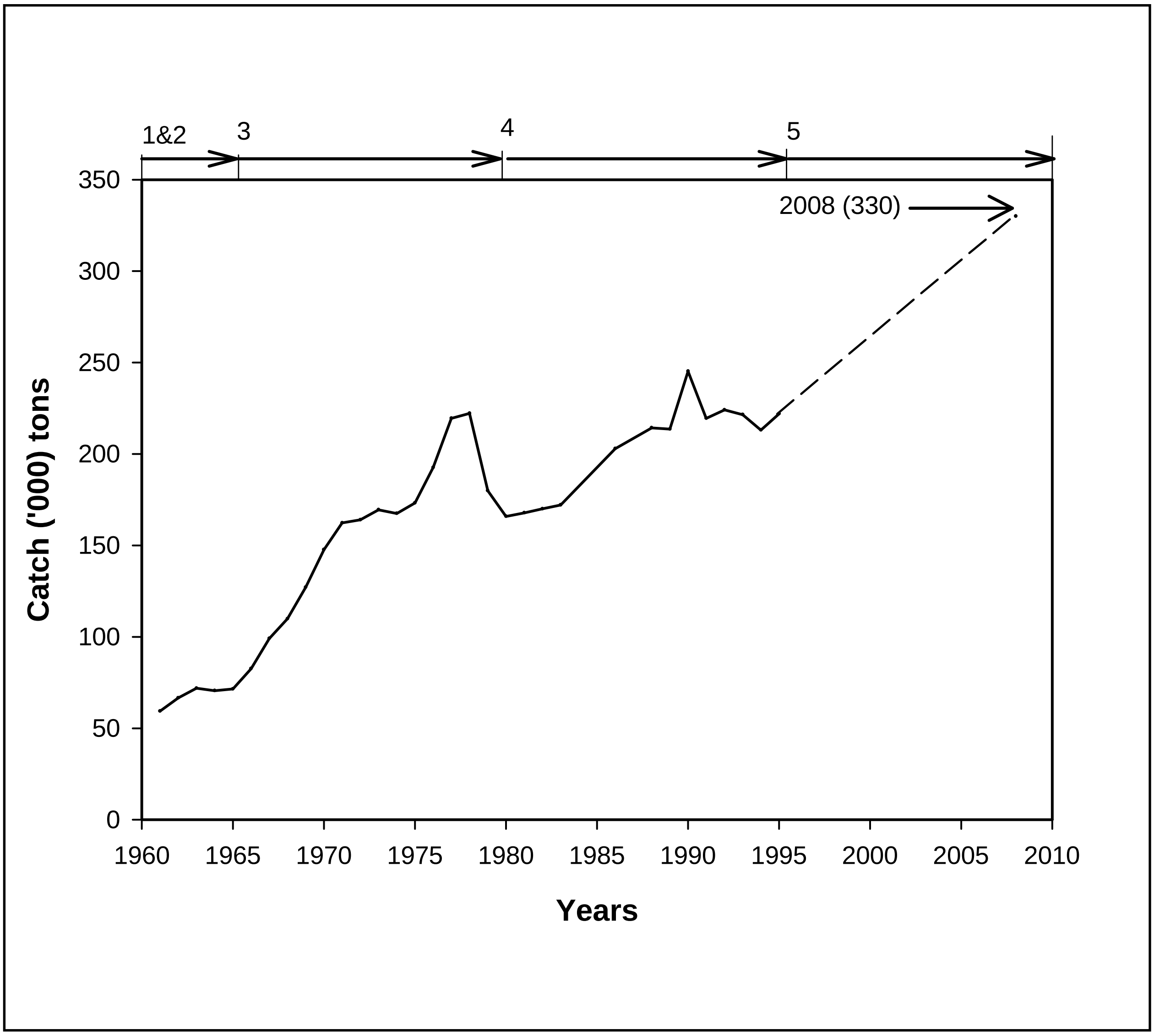

Figure. 1. Changes in annual total fishery yield in Uganda. The period when different stressors are thought to have started influencing the catches are indicated at the top of the figure: 1 = Exploitation (before 1965 onwards); 2 = Water level fluctuations (from 1961 onwards); 3 = Non-native species introductions and eutrophication (1960s onwards); 4 = Climate change (1970s onwards; and 5 = Water hyacinth (1989 - 1992)]

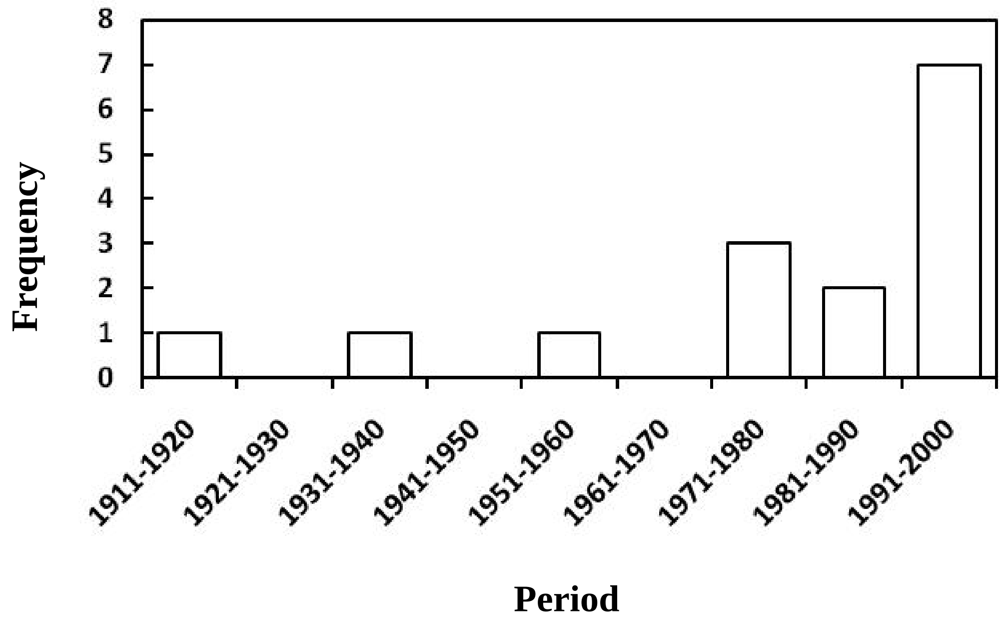

Figure 2. Frequency of droughts in Uganda between 1911 and 2000 suggesting that climate factors started to manifest around 1970s and became more intense after 1990s (Based on GoU, 2007)

Figure 3. The average water level at Bugondo on Lake Kyoga (broken line) and Masindi Port downstream on the Nile (solid line) in January 1948 - 2003. Data from Directorate of Water Resources Management.ake Kyoga

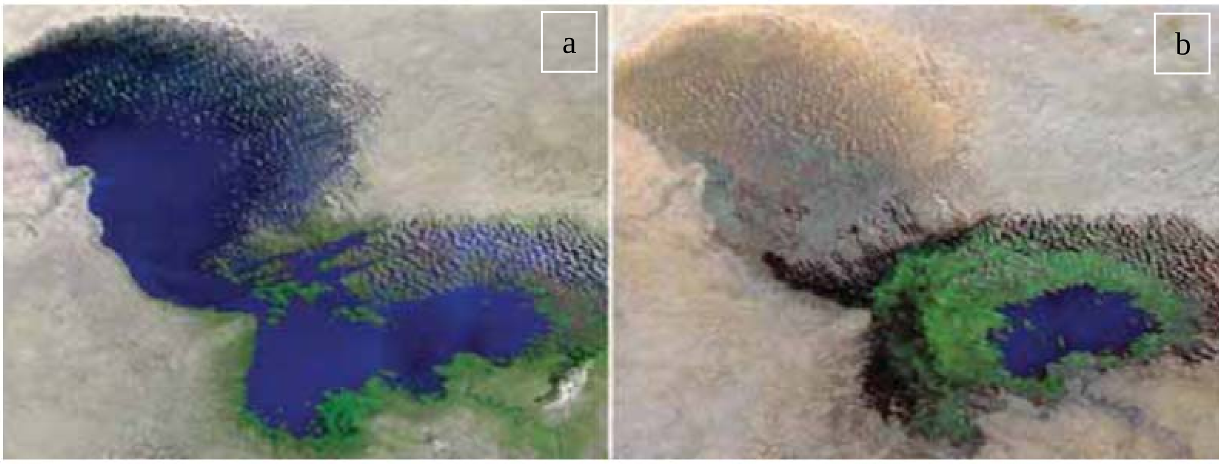

Figure 4. The area of Lake Chad in 1973 (a) and 1978 (b). Lake Chad in Chad, Cameroon, Niger and Nigeria was once one of the largest lakes in Africa but extensive irrigation projects, expanding desert and increasing dry climate have shrunk it to 5% its former size (Source: Barenge & Perry 2009)

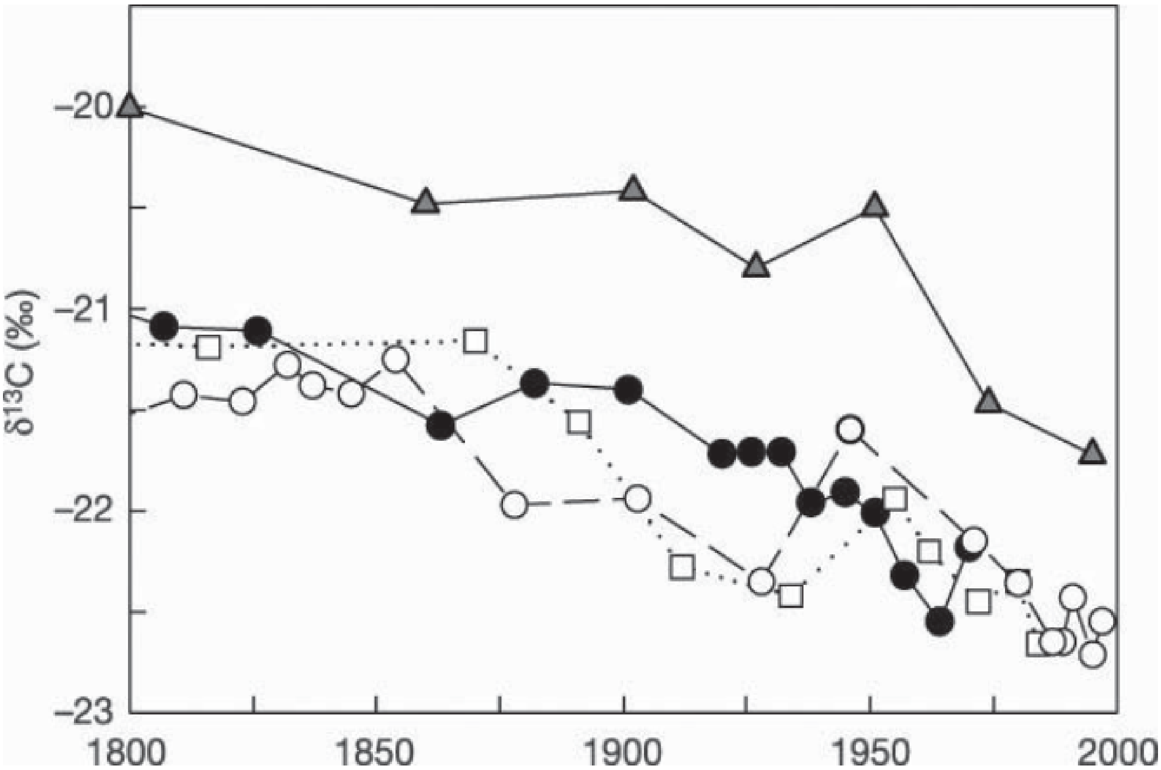

Figure 5. Phytoplankton productivity in Lake Tanganyika has decreased over time and this was more pronounsed after the 1950s with increase warming and has been associated with a 30% decrease in fishery yield (Source O'Reilly *et al*., 2003)

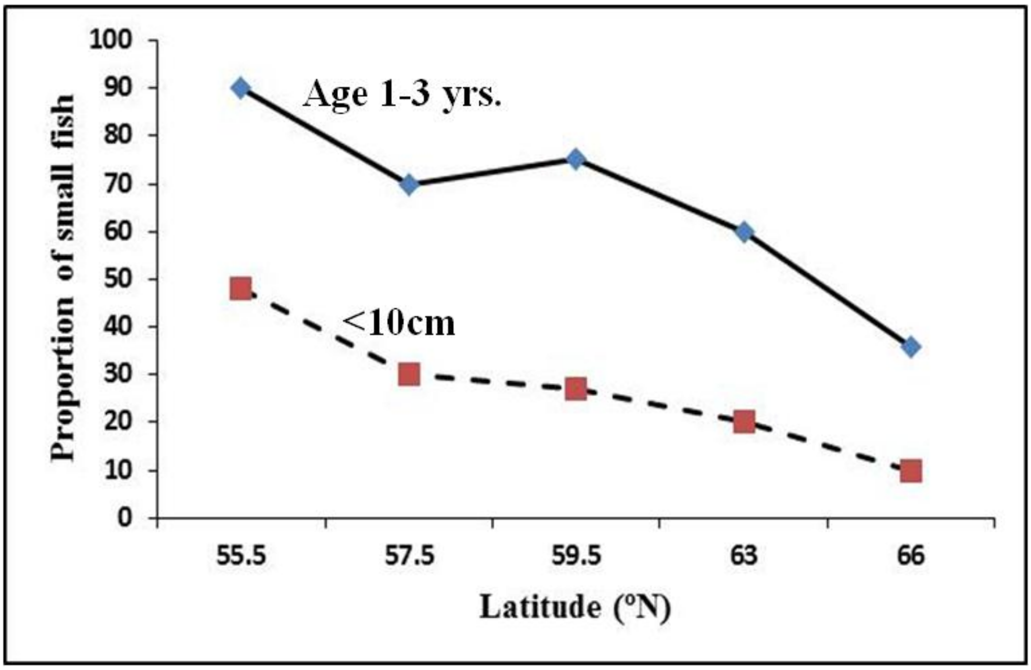

Figure 6: Changes in the proportion of small <10 cm of total catches, and age 1–3 (of total catches by number) specimens of perch in multimesh sized gillnets in 50 Swedish lakes, averaging data from 2 to 14 years in the different lakes. (Jeppesen *et al*., 2010)

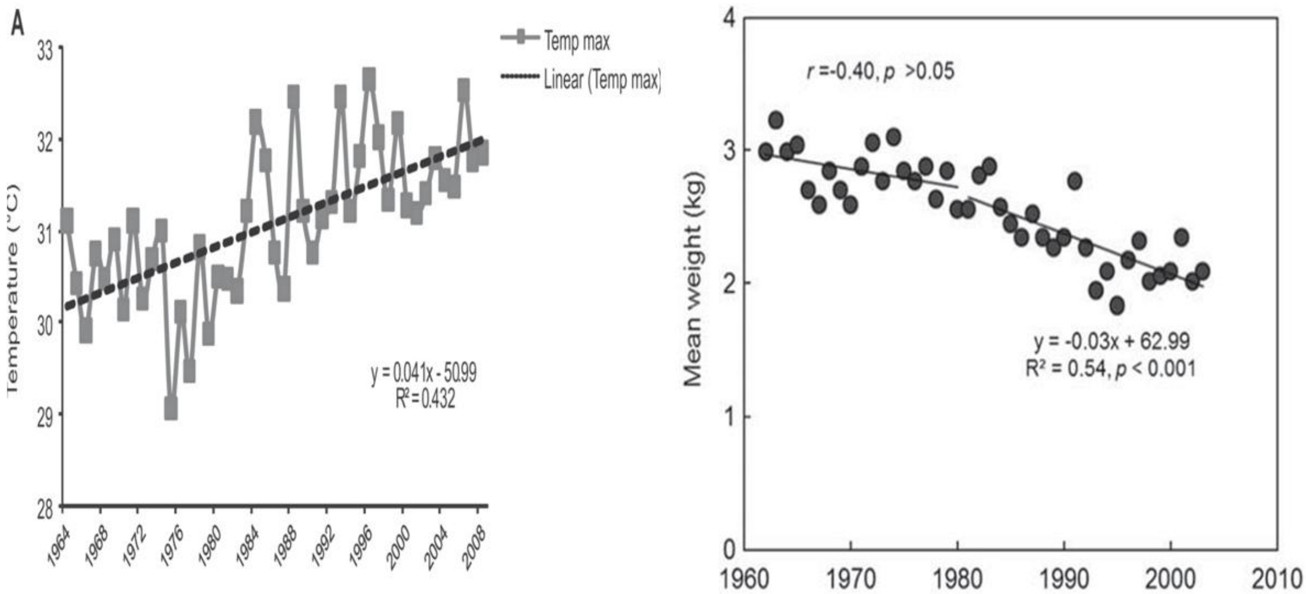

Figure 7: Average increase in water temperature of lake Kariba and the corresponding adjustments in mean weight of fish harvested (Adapted from Ndebere-murisa *et al*., 2011)

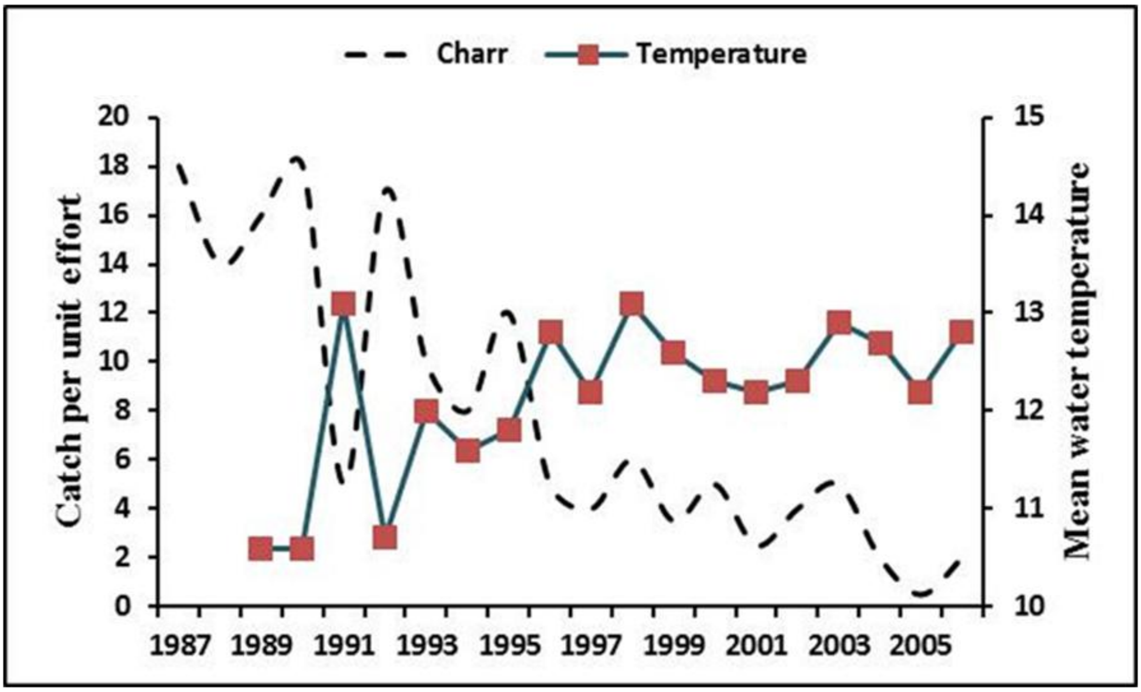

Figure 8: CPUE (Average number of fish caught per net) of Arctic charr and average water temperature in Lake Elliðavatn. r=-0.87, p<0.05. (Modified from Jeppesen *et al*., 2010)

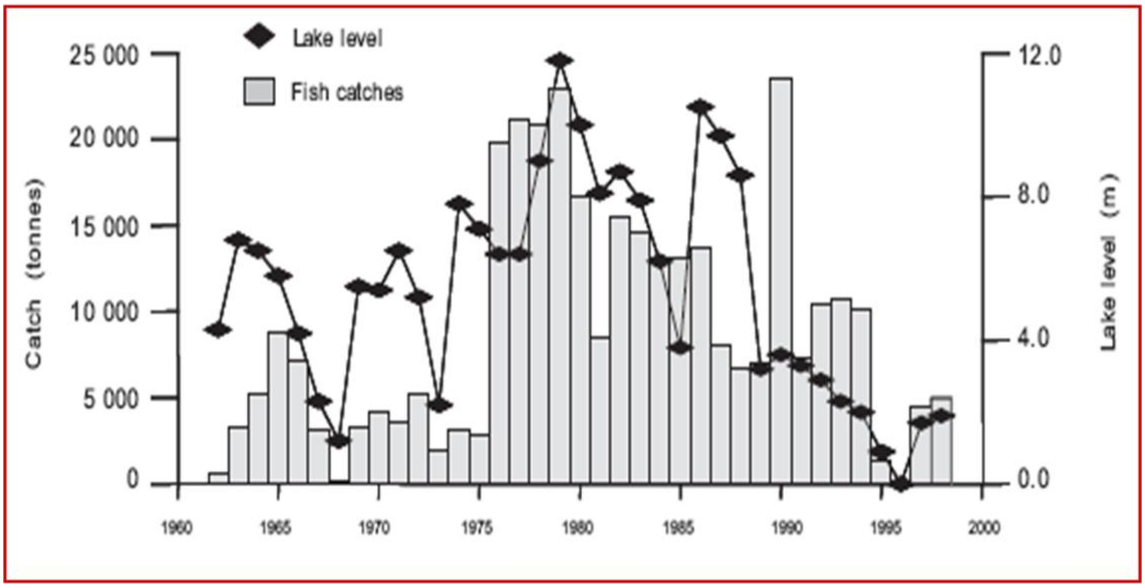

Figure 9: On Lake Chilwa, fluctuations in water levels were strongly related to fishery yield (Allison *et al*., 2007).

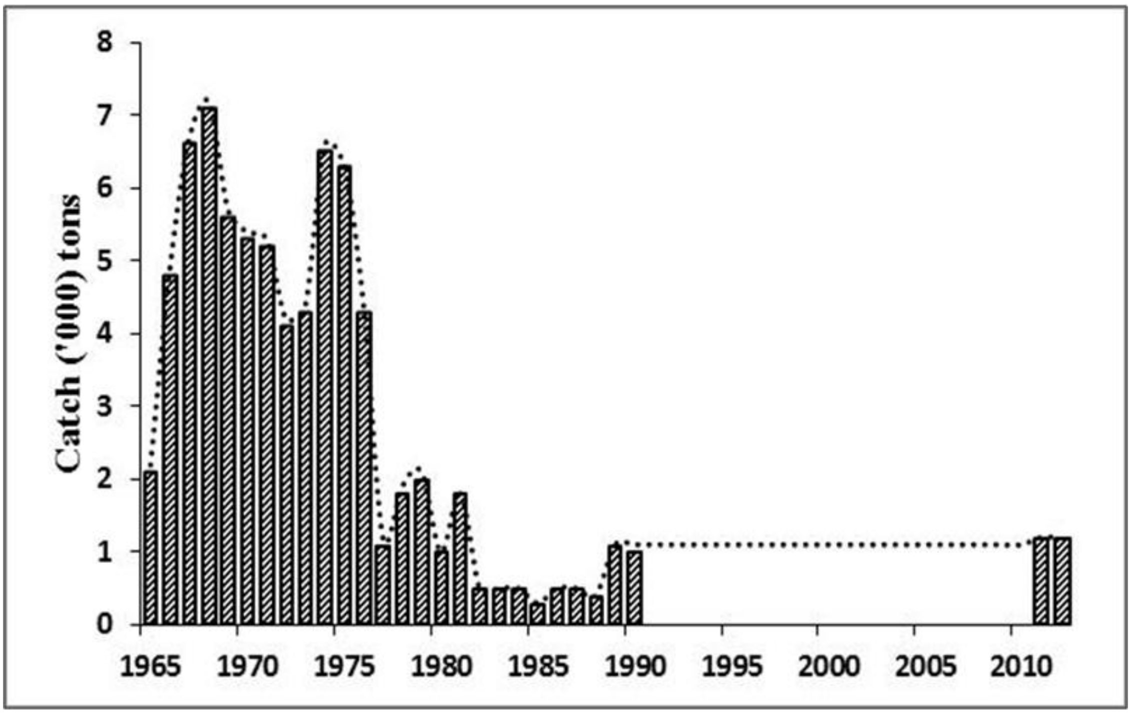

Figure 10: Changes in fishery yield in Lake Wamala