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The impact of climate change on fisheries in the tropics

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Abstract
This paper reviews the impacts of climate change on fisheries, with particular reference to the tropics to assess what happens to the aquatic life in different ecosystems as the climate changes. The general effects of climate change on freshwater systems are likely to be increased water temperatures, decreased dissolved oxygen levels, change in perception and other variables, such as wind velocity, wave action and flooding, which can bring about significant ecological and biological changes to freshwater ecosystems. Furthermore, some anthropogenic responses to climate change (improper water utilization, distraction of freshwater side vegetation, improper wetland resource utilization) will exacerbate its already-detrimental effects. This could alter food webs and change habitat availability and quality. Fish physiology is inextricably linked to temperature and other environmental factors that fish have evolved to cope with specific hydrologic regimes and habitat niches. Therefore, their physiology and life histories will be affected by alterations induced by climate change. Therefore, proactive management strategies such as strengthening of capacity, governments and civil society; Supporting adaptation and mitigation measures by rural/urban people particularly the most vulnerable sectors of the society; Adding value to existing adaptation and mitigation initiatives to enable tropical scientists to apply expertise and carry out research in support of adaptation projects in land-water interface ecosystem; Increasing awareness of all stakeholders, including policy makers; and improving on efficient use of current use of water and water-related resources, including fisheries will be necessary to sustain tropical fisheries.

Keywords: Climate change impacts, fisheries, freshwater, tropics

1. Introduction

Climate change is environmental change that is fundamentally caused by human developmental efforts and in return also calls for mitigation efforts to fit human efforts into the new climatic variations. Climatic changes that may occur locally eventually cut across boundaries to cause global impacts [22]. According to the International Panel on Climate Change (IPCC) report, by 2100 global average temperature would be raised 1.4 to 5.8 ^{0}C and precipitation would vary up to ±20% from the 1990 level. Being one of the very sensitive sectors that impact human livelihoods, climate change can cause significant impacts on water resources, particularly fresh waters that are the most pivotal resources for development.

Climate change affecting certain components of the hydrological cycle, especially precipitation and runoff, a change in climate can alter the spatial and temporal availability of natural resources including fishery. The climatic impact on the water regime may also exacerbate other environmental and social effects of fisheries management [21]. Based on these impact expected to affect most the livelihoods, health, and educational opportunities of people living in poverty, as well as their chances of survival, both locally in specific areas and globally in general.

As stated above, developing countries will be more vulnerable to climate change impacts mainly because of the larger dependency of their economy on agriculture. Some anticipated consequences include falling productivity, species migration and localized extinctions, as well as conflicts over the use of scarce freshwater resources and increased risks associated with more extreme climatic events such as hurricanes or reduced in precipitation patterns. These results direct impacts on aquatic ecosystem on which they depend, such as changes in the chemistry and quantity of fresh waters available for development.

The precise and localized impacts of climate change on fisheries are, however, still poorly understood [54, 46, 13]. This is because "the inherent unpredictability of climate change and the links that entwine fishery livelihoods with other livelihood strategies and economic sectors make unraveling the exact mechanisms of climate impacts hugely complex" [55].

Furthermore, tropical fisheries, which are the most important to small-scale fishers in developing countries, have received less scientific study than those in the waters of developed countries [43].

Climate change is projected to impact broadly across ecosystems, societies and economic orders, increasing pressure on all livelihoods and food supplies, including those in the fisheries sector. There is an urgent need to better understand where climate change is most likely to reduce livelihood options for fishers and where there is therefore the greatest need to invest in alternative rural and urban enterprises.

In addition, information has been lacking in tropical areas and where people are most likely to be vulnerable to climate-induced changes in fisheries. This information is required for the effective prioritization of development interventions to reduce vulnerability to the impacts of adverse climate change on fisher folks living in poverty. The fisheries sector makes important contributions to local development in lakeshore and floodplain areas, through employment and multiplier effects. Maintaining or enhancing the benefits of fisheries in the context of changing climate regimes is an important development challenge in the tropics. The objectives of this paper are therefore; to annotate what happens to the aquatic life in different ecosystems as the climate changes.

2. The importance of fisheries

2.1 Livelihoods: The livelihoods of about 520 million people around the world depend on fisheries and aquaculture [15], 98% of whom live in developing countries [52]. FAO data reported by the World Bank (2005) indicates that the number of fishers in the world has grown by 400% since 1950, compared with a 35% increase in the number of agricultural workers over the same period. Most of the growth has been in small-scale fisheries in the developing world. It is likely that more poor people will turn to fishing and other common-pool resources in future as a result of the negative impacts of climate change on agriculture and other sectors.

2.2 Trade: Fish is one of the most widely traded foodstuff in the world, making 37% of fish produced (live weight equivalent) and is traded internationally [14]. In 2006 exports of fish were worth a total of $85.9 billion [15], more than half of which originated in developing countries. In 2002, net exports of fish generated more foreign exchange earnings for developing countries than rice, coffee, sugar, and tea combined (World Bank 2005). Aquaculture has grown by 6.9% per annum since 1970 [14] and now provides half of global fish supply [39]. As global demand continues to grow, there are opportunities for poverty reduction within the sector if supplies of wild fish can be maintained and aquaculture expanded sustainably.

2.3 Health and nutrition: One third of the world's population rely on fish and other aquatic products for at least 20% of their protein intake [11] and fish provides more than 50% of all the protein and minerals consumed by 400 million of the world's poorest people [48] and is also an important source of other nutrients such as vitamins A, B and D, calcium, iron and iodine. Even in small quantities, fish can have a positive effect on nutritional status by providing essential amino acids that are deficient in staple foods such as rice or cassava. Fish accounts for 30% of animal protein consumed in Asia and 20% in Africa [42]. It is, thus, central to the food security of many of the world's poor, especially in coastal areas and Small Island developing states.

3. Tropical fishes and the environment

Tropical fishes have high critical thermal maxima [45] and an ability to adjust to increasing temperatures. Zebrafish (*Danio rerio*) embryos reared at 33 ^{0}C produced more heat shock proteins than those held at 21 ^{0}C or 26 ^{0}C, to cope with thermal stress [23]. Instead of having exceedingly high metabolic rates and energy demands, tropical fish held at their optimal temperatures have metabolic rates similar to those of temperate fishes [49]. Given such information and the fact that current climate change scenarios predict temperature increase for the tropics [24], it seems possible that tropical fish will not suffer the effects of climate change as much as temperate fishes.

Though tropical fishes can currently endure these temperatures [36], a slight increase of 1-2 ^{0}C in regional temperatures may cause the daily temperature maxima to exceed these limits, particularly for populations that currently exist in thermally marginal habitats [43]. Recent work by (Chatterjee, 2004) on common carp and rohu (*Labeo rohita*), important eurythermal aquaculture species on the Indian subcontinent, showed increased tolerance to elevated temperatures following acclimation to water temperatures of 30 ^{0}C and 35 ^{0}C. This suggests that there may be physiological adjustments to a new climate by eurythermal species in low latitudes. However, for fish currently living in marginal habitats, the effects of global warming would be similar to those predicted for temperate systems because tropical fish exhibit similar physiological symptoms when subjected to elevated temperatures. In a laboratory study of temperature and swimming costs, Nile tilapia (*Oreochromis niloticus*) experienced higher oxygen debts after exhaustive exercise at 33 ^{0}C than 23 ^{0}C. Some studies indicate that tropical fishes are resilient to poor environmental conditions such as high temperatures and low levels of dissolved oxygen [31, 51, 49], but there is considerable uncertainty regarding the direction and magnitude of the possible changes to their environment [24].

4. Impact of climate change on fisheries

The links between fisheries and their ecosystems are deeper and more significant than those that exist in mainstream agriculture [15]. The productivity of a fishery is tied to the health and functioning of the ecosystems on which it depends for food, habitat and even seed dispersal [34] generally the only control humans can exert over a fishery's productivity is adjustment of fishing effort [5]. Fish also tend to live near their tolerance limits of a range of factors; as a result, increased temperature, lower dissolved oxygen and changes to salinity can have deleterious effects [43].

4.1 General effects

4.1.1 Increased temperature: All freshwater fishes are exotherms that cannot regulate their body temperature through physiological means [37] and whose body temperatures are virtually identical to their environmental temperatures. These fishes may thermoregulate behaviorally, by selecting thermally heterogeneous microhabitats [6, 7], but they are constrained by the range of temperatures available in the environment. Because biochemical reaction rates vary as a function of body temperature, all aspects of an individual fish's physiology, including growth, reproduction, and activities are directly influenced by changes in temperature [53; 44; 18]. Therefore, increasing temperatures can affect individual fish by altering physiological functions such as thermal tolerance, growth, metabolism, food consumption, reproductive success, and the ability to maintain internal homeostasis in the face of a variable external environment [19]. Fish populations that are faced with changing thermal regimes may increase or decrease in abundance, experience range expansions or contractions, or face extinction.

In addition, temperatures below the optimal range slow the rate of metabolism and, if too low, can become lethal. Temperatures above the optimal range increase metabolism and, because warmer water contains less dissolved oxygen, a thermal threshold is reached where respiratory demand exceeds the capacity for oxygen uptake. There are some dramatic examples of how stratification also affects fisheries productivity in tropical systems. Because tropical water temperatures do not fluctuate seasonally as in temperate and subtropical zones, turnover, and therefore, nutrient cycling to the biota of the lake, is a function of wind-induced mixing [32; 50]. Tropical systems such as the African Rift Lakes contain anoxic hypolimnia [29; 3]. The anoxic hypolimnia of tropical lakes also contain high concentrations of hydrogen sulfide [51; 49]. Hydrogen sulfide is a byproduct of anaerobic decomposition of organic matter and is highly toxic to fish. Moderate amounts of mixing allow nutrient influx into the epilimnion and benefit fisheries productivity without introducing high concentrations of toxic hydrogen sulfide into the epilimnion.

In addition, increase in temperature may enhance eutrophic conditions by stimulating explosive macrophyte growth. A 2002 study found that a 2-3 ^{0}C temperature increase could cause a 300-500% increase in shoot biomass of some aquatic macrophyte [27]. A biomass increase of this magnitude would affect the system in various ways. First, because macrophytes take up the phosphorus sequestered in the sediment, the amount of phosphorus immediately available for other primary producers would decline. However, when the macrophytes die and decompose, they release nutrients such as nitrogen and phosphorus into the water column [10; 27]. This influx of nutrients can stimulate algal blooms and help perpetuate high macrophyte production and the likelihood of anoxia-related fish kills [30]. Hence, temperature is one of the primary environmental factors on the production of fishes.

4.1.2 Changes in precipitation: Changes in precipitation quantity, location and timing that alter water availability are collectively can alter abundance and composition of fish stock and impact on seed availability for recruitment. Changes in lake water level can alter spawning and recruitment of endemic fish species. Lower water level leads to low water quality due to reduced capacity of productivity of photosynthetic balance. Fish often seek optimal temperature and salinity regimes, while avoiding suboptimal conditions. Thus, ocean and freshwater changes as a result of projected climate change can lead to distributional changes. The biology and ecology of fish in large rivers are strongly linked to the hydrological regime in the main channel and the regular flooding of their adjacent floodplains. The absolute and relative abundance and biomass of species of fish inhabiting large rivers are predicted to change in response to both natural intra-annual variations in flooding regimes as well as long-term climatic shifts [16]. A change in precipitation averages and potentially increases in seasonal and annual variability and extremes are likely to be the most significant drivers of change in inland fisheries [55].

4.1.3 Decreased dissolved oxygen: Biologically available dissolved oxygen (DO) is much less concentrated in water than in air. Oxygen enters the water column through diffusion from the atmosphere and by photosynthetic production of aquatic plant life. Plant, animal, and microbial aerobic respiration of aquatic organisms may decrease DO in the water column, especially at night when photosynthesis stops. Oxygen solubility in water has an inverse relationship with water temperature. Because the aerobic metabolic rates of most cold-blooded aquatic organisms increase with temperature, an increase in temperature both decreases the DO supply (through reduced saturation concentrations relative to air) and increases the biological oxygen demand [47].

As observed by Gerdaux (1998), an increase in mean temperature affects hypolimnetic dissolved oxygen concentrations in two ways: increased metabolism of fish and other organisms in a slightly warmer hypolimnion lead to the faster depletion of the limited oxygen supply, and Lake Overturn, the primary means of replenishing hypolimnetic dissolved oxygen, occur less frequently. More pronounced and longer-lasting stratification will reduce the amount of oxygen exchange to the hypolimnion from the oxygen-rich epilimnion. When the oxygen demand in the hypolimnion exceeds the supply, hypoxic or anoxic conditions occur. Fishes that depend upon these thermal compartments are then faced with a ‘‘temperature-oxygen squeeze’’; they are confined to a habitat whose boundaries are defined by the warm temperatures in the epilimnion and the low levels of dissolved oxygen in the hypolimnion [17]. This severely limits their available spring and summer habitat, because increased ambient temperatures thicken the epilimnion and cause accelerated oxygen depletion in the hypolimnion [9; 20].

4.1.4 Effect on primary production: Primary productivity is affected by availability of nutrients in the water, which in turn depends on external load of the same run-off injections and internal load by lake mixing, as well as levels of light and temperature. In some areas reduced precipitation could lead to reduced run-off from land, starving wetlands and mangroves of nutrients and damaging local fisheries. In other areas increased precipitation or increased extreme weather events, including flooding, will lead to excessive nutrient levels in rivers, lakes and coastal waters as sewage and fertilizer are washed into water bodies causing harmful algal blooms, also known as red tides [43; 12]. With climate change primary productivity is predicted to decline at lower latitudes (FAO 2008a), where the majority of the world’s small-scale fisheries are located, reducing the productivity of the fisheries. In the tropics, wind, precipitation, and stratification may affect trophic status of inland water bodies that consequently change the catch of fishes [41].

4.1.5 Eutrophication: The trophic status of aquatic systems is defined by nutrient concentration. An oligotrophic system has a low nutrient concentration, a mesotrophic system has a moderate nutrient concentration, and a eutrophic system has a high nutrient concentration of more than 30mg PO_4 per liter [26]. The natural trophic state of an aquatic system is a function of volume, water residence time, and nutrient input from the surrounding watershed. However, human activity can also alter the trophic status of aquatic systems through anthropogenic enrichment or nutrient external load [30], and climate change [38; 4]. Most cases of eutrophication results from the input of excess nutrients from urban and agricultural runoffs and from sewage discharges [33; 28; 40]. However, increase in temperature can also augment the productivity of a body of water by increasing algal growth, bacterial metabolism, and nutrient cycling rates [30]. Although the complex relationship between climate change and eutrophication makes prediction difficult, increased temperatures will likely result in a general increase in lake trophic status [1]. Lower stream flows could increase water residence times and reduce flushing of nutrients from lake systems, thereby increasing trophic status [4]. When coupled with the input of anthropogenic pollutants, climate change can accelerate the eutrophication process [1] or delay recovery from anthropogenic eutrophication [40; 25]. On the other hand, climate change could reduce anthropogenic eutrophication; increased strength and duration of stratification could lead to an increased sequestration of nutrients in the hypolimnion, where they are not biologically available to primary producers. Likewise, an increase in stream flows and pollutant flushing rates could reduce eutrophication rates [35].

5. Pathways of impact of climate change on fisheries

Climate change can impact fisheries through multiple pathways. Changes in water temperature, precipitation and other variables, such as wind velocity, wave action and flooding, can bring about significant ecological and biological changes to freshwater ecosystems' functions. Extreme weather events may also disrupt fishing operations and land-based infrastructure, while fluctuations of fishery production and other natural resources can have an impact on livelihoods strategies and outcomes of fishing communities.

Some of the pathways identified in the report of Adrian *et al* (1995) are impacts of water temperature change on aquatic ecology: shifting range of fish species, change in inland water currents affecting upwelling zone fisheries and disruption to fish reproductive patterns and migratory routes. An increase in mean temperature may also affect the dissolved oxygen concentrations in the layer of water below the thermocline (hypolimnion) in two ways: increased metabolism of fish and other organisms in a slightly warmer hypolimnion will lead to the faster depletion of the limited oxygen supply, and lake overturn, the primary means of replenishing hypolimnetic dissolved oxygen, will occur less frequently [17]. The other is precipitation and evapotranspiration change the hydrology of inland waters such as river flows and flood timing and such impacts change affect fish reproduction, growth and mortality, as well as other elements of wetland-based biological processes.

6. Conclusion and recommendations

Fresh waters provide globally significant social, economic and environmental benefits. Proliferations of aquatic organisms are influenced by changes in circulation, ventilation, and stratification through changes in temperature, light, and nutrient supply. Alterations of any of these drivers may lead to changes in species abundance and composition, possibly leading to large-scale regime shifts and species migrations or even biomass reductions. As discussed above, climate change will have significant impacts on fisheries. At low latitudes these are likely to be largely negative for fisheries, damaging important ecosystems such as littoral life and mangroves and causing reductions in fish stocks due to rising water temperatures and reduced primary production. This could have significant effects on food security and employment in areas dependent on fisheries that are particularly vulnerable to the impacts of climate change; these include freshwater fisheries of shallow lakes or wetlands and fisheries in other enclosed or semi-enclosed bodies of water. However, some areas may experience localized increases in fish stocks due to in-migration of species from other areas and rising primary production.

A wide range of adaptations and mitigation measures are possible that are either carried out in anticipation of future effects or in response to climate change impacts. In general, responses to direct impacts of extreme events on fisheries infrastructure and communities are likely to be more effective if they are anticipatory, as part of long-term integrated management plan. However, preparation should be commensurate with risk, as excessive protective measures could themselves have negative social and economic impacts [13]. There is a critical need for well informed public policy to address mitigation of green house gas (GHG) emissions to limit and minimize impacts of climate change. To safeguard benefits in the fisheries sector are important factors to be considered. Sound public policy also will be required for climate change adaptation in order to reduce ecosystem vulnerability, provide information for planning and stimulating adaptation and mitigation measures, and ensure that adaptation actions do not have negative effects on other ecosystem services and the longer term viability of fisheries. This paper therefore recommends that strengthening of capacity, supporting adaptation and mitigation measures by rural/urban people particularly the most vulnerable sectors of the society, adding value to existing adaptation and mitigation initiatives to enable tropical scientists to apply expertise and carry out research in support of adaptation projects in land-water interface ecosystem, improve on efficient use of current use of water and water-related resources, including fisheries and finally engaging all water, fisheries resources users and the general wetland users in developing concerted sustainable water and water-related resources.

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