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THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON FRESHWATER FISH, FISH CULTURE AND FISHING COMMUNITIES

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ABSTRACT – The decline of global fish production in many parts of the world are widely documented as fishing down the foodweb or overfishing, together with climate change, this may lead to further decline of fisheries production and food insecurity. In this paper, the authors discussed climate change impacts on freshwater ecosystems which are predicted to be diverse and widespread affecting change in temperature, water flow and quality and hydrological regimes, and changes to the biodiversity of both endemic and non-native species. Climate change may also exacerbate existing problems affecting freshwater ecosystems and has significant negative impact on freshwater fisheries. Since fish are poikilothermic animals strongly affected by ambient water temperature, the effects of climate change on their physiology and behavior will be particularly pronounced, in particular to fish growth, metabolism, food consumption, reproductive success and habitat range. Inland fisheries and aquaculture, which forms an integral part of many rural livelihood systems will be severely impacted by drought, changing water levels and flooding events. These changes need focused strategies to mitigate and cushion the impending impacts of a climate change. A general strategy in conservation efforts would be enhanced protection of watershed areas, a combination of government and community-based partnerships in implementing protection measures of natural habitats such as rivers, lakes, marshes, and other coastal habitats as anticipatory measures on possible impacts of climate change.

Keywords: climate change, freshwater fisheries, fishing communities, Philippines, typhoons

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Introduction

Growth in global fish production is mainly fuelled by fish culture of few major commercially valuable species in various parts of the world such as Atlantic salmon, catfish, various carp and tilapia species, shrimps, molluscs and seaweeds (FAO 2014). The global decline in capture fisheries production has been debated and overfishing has been implicated as a major cause of the decline apart from pollution, rapid urbanization and high population growth rates that put pressure on the ecological services and functions of natural resources (Pauly and others 1998; Pauly and others 2000; Pauly and others 2002; Vitousek and others 1997). On top of this, the report of Intergovernmental Panel on Climate Change (IPCC 2007) recognizes that human induced warming temperature on lakes and rivers pose serious threats to various fish species and fish culture production (Cheung and others 2009; Cheung and others 2010; Ficke and others 2007). With climate projections of warm ocean, acidic waters, and species range redistribution the climate change effects on freshwater ecosystems are not that far different, with alterations to water temperature, water flow and hydrological regimes, modifications to water quality, toxicity and changes to the relative success of non-native species (Moyle and others 2013; Schindler 2001; Sharma and others 2011). This may also exacerbate problems affecting freshwater ecosystems which has significant negative impacts on freshwater fisheries. Since fishes are poikilothermic animals affected strongly by ambient water temperature, the effects of climate change on their ecology and behavior are likely to be particularly pronounced and widespread, with changes to temperature regimes being of fundamental importance (Baisez and others 2011; Sfakianakis and others 2012; Shanley and others 2014). Observed global temperature readings among the world's meteorological stations show that there is increasing trend which has been positively identified to be related to global CO_2 emissions, primarily from electricity, heating and transportation sectors (IPCC 2007; Pilli-Sihvola and others 2010; Wright and Fulton 2005). Inland fisheries which are artisanal fisheries will be particularly affected by changing water levels and increasing incidence of dry spells as well as flooding events (Katikiro and Macusi 2012; Xenopoulos and others 2005). This further hinders our ability to make predictions about changing temperatures, precipitation patterns, and seasonal variability. A significant climatic shift, such as decrease in rainfall levels and change in seasons will affect freshwater fish communities thereby affecting fisheries production.

Climate change impact on various fish species will include species range expansion or decrease of habitat area through a number of mechanisms, with temperature having a dominant effect among various environmental factors but which may not necessarily operate independently with the possibility of synergy or interactions between factors being certain (Daw and others 2009; Pörtner and Farrell 2008). In general, the effects of climate change on freshwater ecosystems and associated human communities are already presented in literature (Deepananda and Macusi 2012; Katikiro and Macusi 2012; Schindler 2001). For the purpose of this review, the focus is on the current effects of climate change on freshwater fish, culture-based fisheries and fish farming communities of aquatic ecosystems (e.g. rivers and lakes) and their effects on ecological services provisioning of these freshwater ecosystems and adaptation to these effects.

Materials and Methods

A systematic review of climate change effects on aquatic ecosystems, freshwater in specific to deduce the predicted changes and associated outcomes are presented. Through literature search in google scholar and other online sources, information was searched under the following general keywords: climate change, freshwater fisheries, freshwater fish production, fish farming, and response to changes.

Results and Discussion

Impacts on freshwater finfish

Fish is critically important for food security and wellbeing of human population (Béné and others 2015). The global fisheries production in 2012 was 158 million metric tons, of this, capture fisheries production contributed 91 million metric tons, and aquaculture produced the remaining 67 million metric tons (FAO 2014). In most debates about food security issues, sometimes fish production is left out and undiscussed, however essential it is for livelihood and food security of millions of women and men in low income families (Allison 2011; Béné and others 2015). In terms of utilization of fisheries production, 86% (136 million tons) was utilized for human consumption while the rest, 14% (21.7 million tons) was used for non-food purposes for instance in fish meal and fish oil or ornamental purposes (FAO 2014). For the utilization as human consumption, about 61 million tons of the global fish production was utilized as a live/fresh/chilled food fish in developing countries and about 1 million tons was used in developed countries (Figure 1; FAO 2014). Most of these food production come from aquaculture production which has been termed as blue revolution with capture fisheries stagnating at 91 million metric tons, it is now contended that fish production through culture of bivalves, crustaceans, fish and seaweeds will help sustain billions of humanity in the years to come (Duarte and others 2009). In terms of frozen fish, about 27 million tons was utilized in developing countries and 13 million tons in developed countries. The per capita fish consumption of the world increased from 9.9 kg in the 1960s to 17.0 kg in 2000 and 18.9 kg in 2010 and 19.2 kg in 2012, proving that fish food is now the highest animal protein source among the poor, income-wise but food deficient (Béné and others 2015). In Southeast Asia, this increased from 12.8 kg in 1960s to 33.4 kg in 2010 or about two-thirds (FAO 2014). Given this great dependence on fish food consumption, it is critical to look at the possible impacts of climate change and to have new perspectives on which of the fisheries could be vulnerable and what measures can be used to mitigate its effects.

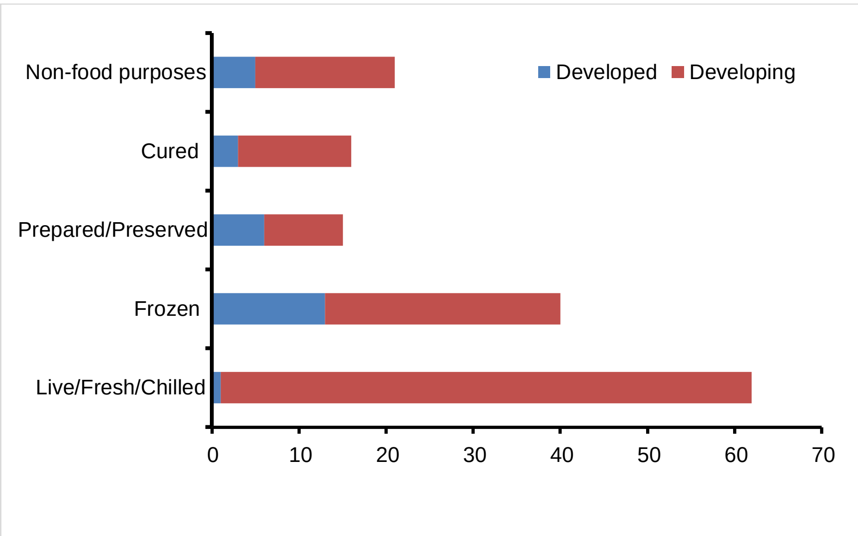

Figure 1. Utilization of world fisheries production between developed and developing countries (source: FAO 2014).

Significant variations in climate on inter-annual and decadal changes of time scales can cause notable changes in distribution of fish, mediate their reproduction success, recruitment, survival and growth (Deepananda and Macusi 2012; Perry and others 2005). In many cases, streams, rivers and lakes may experience reduction in biodiversity of its fish population due to eutrophic conditions and temperate areas will experience shifts from cold adapted species to cool and warm adapted species (Buisson and others 2010; Zafaralla and others 2005). Collectively, these effects can alter availability of fish with consequences that will impact millions of people engaged directly with fishing and would significantly limit the availability of fish for food and income (McClanahan and others 2015; Tirado and others 2015)

Further, the combination of rising sea-level, changes in precipitation, intensive agriculture and aquaculture methods, stream channelization, dam catchments and rapid urbanization and population growth in many countries of the world may likely have major impacts on the functioning of lakes and river systems as fish shelter and nursery grounds (Pringle 2000; Rosenberg and others 2000; Vörösmarty and others 2000). The direct effects on distribution and availability of fish, are not the only ways in which change in climate will affect freshwater fish and eventually their abundance. The indirect effects of climate change may also include geomorphological alterations of lake and river systems due to nutrient run off, mine extraction wastes (toxicity) that lead to eutrophication, acidification, salinization, chemical pollutants and biological invasions (Abreo and others 2015; Liu and others 2015). Rapid urbanization and high population growth rates near lakes and rivers for instance can put excessive amounts of fertilizer and pollutants into lakes used for fish culture such as tilapia and milkfish (Vista and others 2006; Zafaralla and others 2005). Chemical pollutants like methyl mercury for example maybe released from mine extraction wastes or the construction of reservoirs which can last for 2-3 decades in the water and transferred by plankton and fish to humans through consumption (Rosenberg and others 1997). Many components of climate change and its synergistic effect with other anthropogenic stressors are expected to have strong indirect effects on the survival of freshwater fish species through modification of the habitats like dam constructions that may facilitate genetic isolation of the species through habitat fragmentation as well as lead to destruction of riparian habitats and floodplains (Pringle 2000; Pringle 2001; Richter and others 1997; Rosenberg and others 2000). The construction of dams can interfere with the fish routing systems by suppressing their olfactory instincts which are responsible for their homing instincts (Eissa and Zaki 2011). As a result this will further erode the biodiversity of fish species living in many small streams, rivers and catchment areas in the wild as dam constructions have been known to be primary destroyers of aquatic habitat and fisheries and extinction of species (Postel and others 1996; Richter and others 1997). Another problem posed by dams include exposure to predators not normally met by the fish in a fast moving body of water and slow or weak species may be in danger of predation (Francisco 2004). Other effects include mismatch of food, habitat and mates as the fish will be placed in a newer environment not previously inhabited (Rosenberg and others 2000).

Other studies focused on investigating current patterns of range shifts in species distribution demonstrating that fish species and invertebrates are notably affected by environmental factors (Cheung and others 2009; Cheung and others 2012; Parmesan and Yohe 2003; Perry and others 2005) and this impacts on abundance of fish species as affected by changes in temperature and acidification (Hoegh-Guldberg and others 2007; Hughes and others 2007; Metzger and others 2007; Pörtner and Farrell 2008; Pörtner and Peck 2010). Fish for instance may thermoregulate by selecting thermally heterogeneous microhabitats but they are constrained by the range of temperatures in their environment (Nielsen and others 1994) because biochemical reactions vary as a function of body temperature affecting fish physiology growth rate, metabolism, food consumption, reproduction and activity

(Ficke and others 2007; Pörtner and Farrell 2008). An increase in temperature will also facilitate decreased absorption of dissolved oxygen in rivers and lakes thereby indirectly affecting phytoplankton and zooplankton abundance which are the nutritional backbone of many fish (Eissa and Zaki 2011). These changes in dissolved oxygen levels will depend on ambient temperature, biological oxygen demand and wind mixing which may decrease or enhance stratification. This condition is known to occur in Taal Lake in the Philippines and in Lake Victoria in Africa with the low levels of oxygen due to hypoxic conditions; this leads to fish kills as hydrogen sulfide is released from the bottom water owing to too much nutrients (Ochumba 1990; Vista and others 2006). The fluctuations in temperature and rainfall changes may also favor shifts in phytoplankton compositions which could have negative impacts on fish culture (Siringan and others 2008). In addition the projected changes in temperature and rainfall patterns may interfere in proper provisioning of lakes and rivers which could cause new patterns of recruitment, distribution of species and directly affecting their survival (Cline and others 2013; Munday and others 2009; Ranåker and others 2012). For instance temperature fluctuations during early fish development may produce different skeletal deformities and higher temperatures may also lead to feminization of fish populations , which will ultimately affect breeding success and will result to extinction of certain species (Eissa and Zaki 2011). Current changes in temperature will also result to increase in anoxic areas in crater lakes and degradation of fish habitat (Ficke and others 2007; Vista and others 2006). All of these point to the issue that climate change is not a country issue but more of a transcontinental issue that would best be addressed by all countries concerned because of the catastrophic consequences of climatic change (Eissa and Zaki 2011).

Impacts of climate change on culture based fishery

The development of a culture-based fishery is based on physical and biological aspects of the water bodies used for culturing (rainfall patterns in the area, depth and water flow), socio-economic conditions of fish farmers, stakeholders and the condition of the communities that live in the vicinity (Cochrane and others 2009; Daw and others 2009). In addition to these aspects, there are other physical (seasonal flow, nutrient discharge to river, rate of erosion, salinity, temperature) and biological factors (fish and phytoplankton biodiversity and abundance) that influences lake or reservoir changes due to climatic change (Azanza and others 2006; Chang and others 1992). These factors which include heavy precipitations and rapid evaporations that changes the depth and surface area of the reservoir are important for determining the water retention period (Strzepek and Smith 1995). Culture based fishery solely depend on the normal pattern of biological and physical factors, and therefore, indigenous knowledge of the culture system plays a vital role in this context.

However, unpredictable climatic change can completely destroy a culture-based fishery given a rapid evapotranspiration rate (Guerrero 1999; Jacobs 1992). An increased evapotranspiration could reduce water volume and quality of habitat available for fish during longer dry season increasing salinity levels and affecting culture periods (Ficke and others 2007). Moreover a higher temperature would also mean longer thermal stratifications particularly in lakes, dams, channels, lagoons and rivers used for culturing fish like tilapia or milkfish and this leads to growth of unfavorable algal assemblages (Azanza and others 2006; Vista and others 2006). This shift in phytoplankton composition negatively impacts aquaculture activities as this newer algal assemblage (e.g. *Anabaena spp., Prorocentrum minimum*) may produce alkaloids toxic to fish or their prey items leading to less food available to fish and the bloom can lead to hypoxic conditions in the culture environment (Azanza and others 2006; Azanza and others 2005; San Diego-McGlone and others 2008; Vista and others 2006).

In the Philippines, heavy rains coincide with release of elevated nutrient levels, suspended solids and chlorophyll *a* stored in bottom water of channels and lakes used for milkfish and tilapia aquaculture, causing an overnight phytoplankton blooms that lead to fish kills (Azanza and others 2006; San Diego-McGlone and others 2008). Heavy rains can also generate floods and storm surge causing reservoirs to over flow, which could cause stocked fingerlings to escape from their fish holding tanks facilitating non-native species introductions (Copp and others 2007; Cunico and Vitule 2014). Extended drought periods are also a natural hazard that can affect culture-based fisheries, shortening the water retention period and increasing temperature of the water which may facilitate disease spread among intensively cultured fish (Hoegh-Guldberg and others 2007). Fish cultures located in water bodies that mainly receive seasonal water from monsoonal rains are more susceptible to unpredictable drought periods compared to those located in upstream of rivers (Allison and others 2005). Heavy evaporation during drought period may also increase the trophic state of a reservoir and thereby affecting the productivity of the lake or reservoir and the fish which may lead to regime shifts due to high nutrient environment (Carpenter and others 2008).

The most sensitive and easily affected aspect of culture-based fishery is fingerling production because culture-based fisheries are greatly dependent on seasonal rains that fill reservoirs during periods of monsoonal rains (Cochrane and others 2009). The composition of carp species used to stock in water-bodies depends on the availability of fingerlings which are produced mainly through artificial insemination. If monsoonal winds become erratic in patterns in the coming years, this may greatly affect the production and availability of fingerling stocks (Capili and others 2005).

The produced fingerlings should be stocked in seasonal and perennial reservoirs at high time to recapture them after growth. Therefore, fingerling production in hatcheries should start at least two months before the monsoon rains. However, present climate changes have affected the reservoirs through changing rainfall and drought patterns and reservoir filling will not proceed with the breeding seasons of the brood stock (Eissa and Zaki 2011). Drought prone regions affected by water availability will negatively impact farmers who rear fingerlings as they will not be able to sell them during the drought years when reservoirs do not fill. Due to climatic change, considerable degrees of risks and uncertainties are involved at virtually every stage of developing a culture-based fishery ranging from production of seed in hatcheries and stocking to harvesting and marketing.

Moreover, with water supply projected to be under stress and extreme weather events increasing in frequency, aquaculture equipment and finfish production in deltaic regions can be obliterated by typhoons or cyclones artificially increasing the costs of production (Lamberts and Kummu 2008; Le and others 2014; Murty and others 1994; Shelton 2014). Siltation caused by floods tend to clog rivers, lakes, drainage systems, reservoirs, dams, irrigation canals and other inland bodies of water which reduces the viability of water resources for economic activities such as fishing, aquaculture, water storage, irrigation, water recreation and water transportation (Faustino-Eslava and others 2013; Israel and Briones 2012). These may lead to spread of invasive species and spread of pathogens to higher latitudes, in the open ocean, coastal areas and in the riparian and lakes environment with potentially catastrophic consequences on the affected ecosystems (Ambrogi 2007; Frenot and others 2005). For instance the introduction of these invasive species may cause extirpation of native species through a more aggressive and competitive behavior than those previously in the lake or river e.g. Nile perch, zebra mussel and rainbow smelt (Sharma and others 2011; Simon and Townsend 2003). On the other hand, some expected positive changes will be increase in growth rates and food conversion efficiencies, longer growing season, range expansion, and the use of new areas for aquaculture (Buisson and others 2008; Crozier and others 2008; Shelton 2014).

Some arising concerns are possible catastrophic combination between climatic forcing and local stressors on communities which exacerbates the present problems of nutrient run-off, chemical pollution, forest clearing for plantations and destruction of mangrove habitats and water impounding operations (Abreo and others 2015; Cuenca and others 2015; Falkenberg and others 2013; Ghedini and others 2013; Rosenberg and others 2000). There are for instance typhoons impacting the present aquaculture facilities in the Bengal region as well as in low lying coastal Vietnam and the Philippines. This dumps water that will swamp fish cages, net pens and other aquaculture structures which inadvertently introduce exotic species that displaces valuable species (Copp and others 2007; Cunico and Vitule 2014).

Impacts of climate change on fishing communities

Fishers which are highly vulnerable to the effects of climate-induced changes to their only resource, fish, fundamentally affecting their livelihoods (Macusi and others 2011; SEI 2003). It is estimated that food insecurity affects more than 795 million people in the world and about 780 million of that are from developing countries which mean that food security is a notable issue that remains to be addressed in different levels by policy and decision makers (FAO 2015). Given that the impacts of physical and biological changes on fisheries and fishing communities will be variable and may both have negative and positive impacts, addressing food security through aquaculture would likely remain one of the arsenals of combating this issue as wheat and rice production may decline in many projected scenarios of climate change impacts (Rice and Garcia 2011). The strength of the impacts depends on the vulnerability of each community, combination of potential impacts (sensitivity and exposure) and adaptive capacity of the communities. Quantifying different threshold levels and adaptive capacity of communities to help decision makers and stakeholders in addressing climate change issues are vital (Allison and others 2008; Liu and others 2015). The thresholds levels for instance of dissolved nutrients such as nitrogen and phosphorous loads, dissolved oxygen and carbon dioxide as well as air and water surface temperatures can be monitored in lake and river systems and used in modelling approaches to provide information to decision makers and stakeholders about their resource (Liu and others 2015). This however needs time to build and appropriate governmental infrastructure to be in place (Papa and Briones 2014) and in some instances, sudden changes in hydrological and lake systems may have dangerous effect on fisher communities and villages located near these affected habitats that are not quickly captured by monitoring systems (for instance the overflow of the Cagayan De Oro river in the Philippines) (Japos and Lubos 2013). In that case, an essential early warning and communication system may therefore be needed apart from direct measurements of threshold levels of physical factors that may involve the fishery such as warning systems on water levels in lakes, river and upstream and mountain and flood prone areas (Faustino-Eslava and others 2013; Lazcano 2009). In addition, early evacuation, house fortification and readily prepared available safe drinking water during emergency situations may reduce the impact of these extreme events (Dinh Ha and others 2013). Other indirect impacts are distribution and marketing costs, changes in sales prices, and possible increases in risks of damage or loss of infrastructure, fishing tools and housing (Allison and others 2008; Cabanban and others 2014). Therefore, fishery-dependent communities may face increased vulnerability in terms of less stable livelihoods, decreases in availability or quality of fish for food, and safety risks due to harsher weather conditions (Badjeck and others 2010). The El Nino phenomenon of 1998-1999 negatively impacted fish culture activities in the Philippines, the total estimated loss was 7.248 billion pesos with the aquaculture sub-sector severely hit with an economic loss of approximately Php 6 million, or 85% of its production capacity followed by marine fisheries (14.78%, Php 1 million) and inland fisheries (0.26%, Php 18,000 pesos) (Guerrero 1999). These heavy losses can be avoided by retooling fishers to go beyond aquaculture when future El Nino events occur (Guerrero 1999).

In addition, worsening storms increase the risks associated with working at lakes, rivers, channels and reservoirs and changes in weather patterns may disrupt fishing operations that are based on traditional knowledge of local weather and current systems (Webster and others 2005). Disruption of other sectors, such as agriculture, tourism and manufacturing by such extreme events may lead to indirect socio-economic effects (Defiesta and Rapera 2014; Faustino-Eslava and others 2013; Israel and Briones 2012). There are many more examples in this context. Drought and flood affecting agriculture may push people out of agriculture and into fishing with labor displacement playing a key role in conflicts over labor opportunities and increased fishing pressure. This was observed as a result of hurricanes in the Caribbean (Mahon 2002) as well as during the recent typhoon Yolanda that ravaged Central Philippines (Cabanban and others 2014). As a stop gap measure to offset local unemployment and to trigger economies, boat building activities, boat and fishing net donations were formulated as livelihood programs of the government in these affected areas (Libre and others 2015; Macusi 2015). Droughts and resultant agricultural failure predicted in some areas of sub-Saharan Africa may lead to so-called “environmental refugees” moving to coastal areas and creating an influx of surplus fishing labor (Conway and others 2005). Moreover it was also observed in Antigua and Barbuda, during Hurricane Luis in 1995 the destruction and damage of tourist infrastructures resulted in the transfer of workers from this sector into fishing for short-term employment, adding pressure to fishing stocks and labor supply (Mahon 2002).

The forecast in Southern Africa is displacement and increased migration that leads to greater variability in lake levels and river flows, affecting lakeshore and river floodplain livelihoods that incorporate fishing (Conway and others 2005). Under increasing uncertainty, migratory fishers becomes a more rational livelihood strategy than investing in a stable village-based existence. Storm and severe weather disturbance can destroy or severely damage infrastructure and equipment such as port, landing sites and boats (Table 1 (Jallow and others 1999). The increasing severity of storms for the past 30 years has been documented (Webster and others 2005).

On the other hand, change in migration routes and biogeography of fish stocks can directly affect fishing effort of fishers, this will have impact on their search and travelling time, thus increasing fuel and ice costs (Mahon 2002). Reduction of catches and collapse of stock due to climate change can lead to unemployment. In Connecticut, catches of lobster fell by 59% between 1999 and 2002 which was linked to increased sea surface temperature in the Gulf of Maine and resulted in the loss of 40% of the lobstermen (Donn 2004).

Species range shift due to climate change in freshwater systems also affects fisher communities adversely. For instance, in the Philippines, aquaculture production is primarily done by stocking fingerlings in lakes and reservoirs and collecting them by organized capture. But climate change may threaten this livelihood through increased natural calamities such as floods, typhoons and nutrient overturning of reservoirs causing fishkills (Escobar and Falcon 2005; Johnson and Harrison 2015; Yamaguchi and Sai 2015). In addition, the shift of the distribution range of freshwater target species may also occur. Although in general, the most common culture species are tilapia, milkfish, carps and catfish in Southeast Asia other freshwater fish species may change their distribution range and thereby leave behind the local businesses such as resorts, restaurants and fishing equipment retailers that depend upon them.

On the other hand, climate change may also have some positive impacts on fisher communities. Climate change increases revenues with increased culture and increased catches of certain species freed from predation and competition of other species that changes in range and in number in the wild (Shelton 2014). This includes intensive culture of tilapia, catfish (pangasius) and milkfish (bangus) both inland and in brackishwater aquaculture. Changes in species abundance can also lead to changes in harvest and processing costs due to retooling (change of gear, boat) to harvest the newly abundant species (Broad and others 1999; Knapp 1998). Artisanal fishermen with limited resources will be particularly affected due to their inability to quickly adapt to new harvesting techniques and tools. Any net increases in overall fisheries yield and associated livelihood benefits such as improved earnings and food security are likely to come at the expense of reductions to species diversity and greater fluctuations in total annual landings and potentially increasing livelihood vulnerability (Cochrane and others 2009; Daw and others 2009).

Unforeseen events leading to reductions in fisheries production will require fishers to further diversify their activities and flexibly exploit other resources as they become available. Thus, their vulnerability to climate change will largely depend on their capacity to adapt. The typically poor status of healthcare system and inadequate facilities found in many coastal developing areas makes fishers vulnerable to extreme events and outbreaks of diseases in these areas as they are unable to pay for these services (Japos and Lubos 2013). Longer and deeper floods might benefit the landless and seasonal fishers, as access to the fishery will remain open for longer periods of time, but drainage congestion and standing water may increase the risk of outbreak of cholera and other waterborne and diarrheal diseases such as malaria, dengue and dysentery (Epstein 2001; Medlock and Vaux 2015). Studies have also shown that the El Niño cycle in certain areas is associated with changes in the risk of diseases transmitted by mosquitoes, such as malaria and dengue fever, and diseases caused by rhabdo viruses other than dengue virus (Hellberg and Chu 2015). The risk of malaria in South America, Central Asia, and Africa (areas where the majority of small scale fishermen are located) has been shown to be sensitive to variability in climate driven by El Niño (Patz and Kovats 2002)

The livelihoods of small-scale fishers are already vulnerable to a range of non-climate risks, including fluctuating resources, loss of access, HIV/AIDS, market fluctuations, conflict, political marginalization and poor governance (Allison and others 2008). This insecurity inhibits investment in long-term strategies for sustainable fisheries and will be exacerbated by additional insecurities caused by climate change impacts. Moreover, injury and death are the direct health impacts often associated with natural disasters linked to climate change events such as increased frequency and severity of floods and hurricanes (Figure 2) (Faustino-Eslava and others 2013; Papa and Briones 2014; Webster and others 2005).

In the case of injury, there is an obvious impact on human capital through the resulting reduction in the physical capabilities of fishermen to pursue their livelihoods (Brunner and others 2009; Wijkstrom 2003). Within communities and households, existing gender issues related to differentiated access to resources and occupational change in markets, distribution and processing, where women currently play a significant role, may be heightened under conditions of stress and increased competition for resources and jobs stemming from climate change. Due to increasing uncertainty of income over time, fisher communities are trying to secure their requirements in difficult economic situations. In some cases, as was in marine fisheries in Peru, because of the decreasing catches, fishers were left without a safety and access to financial resources (Broad and others 1999).

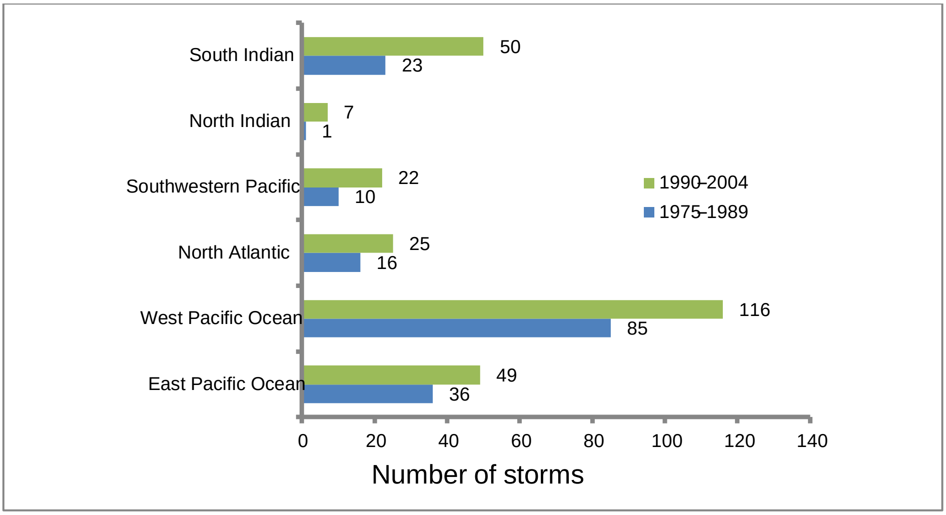

Figure 2. Change in the number of storms for every 14 years from 1975 to 2004 having categories 4 and 5 in different ocean basins (source: Webster and others 2005).

Impacts on food security related to access and availability of important traditional food species can be significant in a scenario of decreased catches due to climate change events (Wijkstrom 2003). The risk of malnutrition and under nutrition for communities highly dependent on fish as a source of protein (Ogutu-Ohwayo and others 1997), combined with changes in diet (reduction of protein from fish source) are some of the possible effects. Decline in commercial fisheries, leading to decrease in income, can dramatically reduce the ability to purchase store-bought food during periods of natural resource scarcity. Fishing operations especially for small scale fisheries can be directly disrupted by poor weather, while extreme events can damage vessels and shore-based infrastructure. City ports and facilities required by larger vessels may be affected.

The socio-economic impacts of climate change can be largely influenced by availability of resources which will impact on fishing cost and income. Climate and weather may affect the availability of fish products in the ways described above. The cost of many inputs into fishing could be affected by increased frequency of storms (e.g. Philippines) causing decrease in availability of resources (Faustino-Eslava and others 2013; Papa and Briones 2014). Increasingly poor weather will also increase cost resulting from increased fuel cost due to increased labor cost and poor working conditions, increasing maintenance cost for vessel and fishing equipment (traps or cages) or cost associated with gear replacement following loss or destruction.

Loss of income will also result when weather conditions are such that it prohibits fishers from going out to lakes and rivers to fish. The unavailability of resources will create further hardships to fishers who are socially and politically marginalized with limited access to food, finance, health care, education and other public services (Emdad and others 2015). Fishers' inability to harvest fish resource may cause them to migrate to urban areas or to cities to increase their chances of earning a living.

Table 1. Summary of potential impacts of climate change on freshwater fish, aquaculture, and fisher communities

Type of fishery	Drivers	Impact	Reference
Freshwater fin fish	Sea-level rise	Loss of coastal fish breeding and nursery habitats e.g. Mangroves and coral reefs	Cuenca and others 2015; Krueger and others 2010; Macusi and others 2011; Pratchett and others 2011;
	Higher water temperatures	Changes in sex ratio	Brown and others 2015; Ospina-Álvarez and Piferrer 2008; Sfakianakis and others 2012;
		Altered time of spawning	Nõges and Järvet 2005; Warren and others 2012
		Altered time of migration	Baisez and others 2011; Pörtner and Farrell 2008; Pörtner and Peck 2010
		Reduced fish abundance	Ficke and others 2007; Pörtner and Peck 2010;
	Extreme weather events (typhoons/floods)	destruction of homes, loss of ports and harbors	Capili and others 2005; Faustino-Eslava and others 2013; Katikiro and Macusi 2012; Webster and others 2005
Culture-based fishery	Droughts	Changes in water levels and physico-chemical properties of lakes, artificial reservoirs and rivers	Ahmed and others 2013; Gronewold and others 2013; Rosenberg and others 2000; Traore and Owiyo 2013
	Higher water temperatures	Thermal stratification, phytoplankton bloom	Azanza and others 2006; San Diego-McGlone and others 2008
	Extreme weather events (typhoons/floods)	Destruction of coastal, fluvial, lacustrine fishing infrastructures; increased chances of release of invasive species	Daw and others 2009; Johnston and Purkis 2015; Pappal and others 2008
Fisher communities	Droughts	Reduced fishing days; reduced fish catch; food scarcity	Abubakar and Yamusa 2013; Gillson and others 2009
	Extreme weather events (supertyphoons)	Reduced chances for fishing; increased chances for fishing accidents	Deepananda 2013; Deepananda and Macusi 2012
		Destruction of productive assets, homes, fishing gears	Albert and Isife 2014

Implications for fisheries

Understanding the effects of climate change on freshwater fish, fish farming and the communities that are dependent on them are of great importance for food, livelihood and adaptation of fishers. Given the variety of impacts due to climatic changes from air, water surface temperatures, rainfall, nutrient run-offs, extreme weather events and species distribution and phenology there is no doubt that measures to mitigate climate change impacts are indispensable. Climate warming has been shown to increase the frequency of extreme weather events increasing natural disasters that have impacts on fisheries production and costs and ultimately on the fisher. The impacts on inland fisheries and fish farming are particularly obvious in the availability of fish for food, income and livelihoods and its ramifications on the social fabric of society.

Conclusion

Climate changes are components of other stressors on the environment and produce actual and potential impacts on fisheries. The effects of climate change on freshwater ecosystems cannot be easily controlled by engineering measures. A general strategy to mitigate the possible negative impacts of these combined stressors would be conservation of fish habitats, including mountain and forest ecosystems that ultimately affect the biota of lake, river and streams. The promotion of protected areas particularly national inland water areas and head water resources through monitoring systems, reforestation programs and community based management measures are focal points of adaptation strategy. Together, in combination with building better infrastructure that are climate proofed will lessen the impact of climate change on communities. The creation and management of protected areas in coastal and deltaic regions is advocated, which includes mangrove reforestations in recognition of their value in reducing the negative influence of climate change as trees act as efficient storage for carbon. The better the condition of wildlife habitats, the more resilient they will become to any natural perturbations as this increases their ability to homeostasis. Other mitigation measures include increasing fuel efficiency of boats used in fishing to minimize the contribution of fisheries to climate change and utilization of waste products from fish processing into biodiesel. Others include creation of protected and buffer zones in rivers and lakes to allow spawning, growth and reproduction of a portion of the fecund female adult fish population in the wild.

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Statement of Authorship

All authors contributed equally to the development of the concept, gathered literature and wrote several versions of the manuscript.

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