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# The Effects of Climate Change on Aquaculture

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***Abstract*—Climate change is an additional pressure on top of the many (fishing pressure, loss of habitat, pollution, disturbance, introduced species) which fish stocks already experience. The impact of climate change must be evaluated in the context of other anthropogenic pressures, which often have much greater and more immediate effect. Factors that can shape climate are climate changes. These include such processes as variations in solar radiation, deviations in the Earth's orbit, mountain-building and continental drift, and changes in greenhouse gas concentrations. Some parts of the climate system, such as the oceans and ice caps, respond slowly in reaction to climate changes because of their large mass. Therefore, the climate system can take centuries or longer to fully respond to new external changes.Many of the studies made assumptions about changes in baseline socioeconomic conditions, adaptation, and biophysical processes. Almost all of the studies we examined estimated that there will be increasing adverse impacts beyond an approximate 3 to 4°C increase in global mean temperature. The studies do not show a consistent relationship between impacts and global mean temperatures between 0 and 3 to 4°C. In coastal resources it is clear that impacts will be adverse with low levels of temperature change.**

***Index Terms*—aquaculture, adaptation, climate change, fisheries, economic, ecosystem, marine, mitigation.**

## I. Introduction

Climate change is a change in the statistical distribution of weather over periods of time that range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average. Climate change may be limited to a specific region, or may occur across the whole Earth.

Climate change may be qualified as anthropogenic climate change, more generally known as "global warming" or "anthropogenic global warming"2.Climate change has both direct and indirect impacts on fish stocks which are exploited commercially. Direct effects act on physiology and behavior and alter growth, reproductive capacity, mortality and distribution. Indirect effects alter the productivity, structure and composition of the marine ecosystems on which fish depend for food.

However, even though the year-on-year rate of anthropogenic climate change may seem slow, this is very rapid compared with previous natural change and the accumulative value produces a significant difference from the "natural" state quite quickly. Climate change impacts such as more frequent and severe floods and droughts will affect the food and water security of many people.

## II. The Impact of Climate Change on Aquatic Ecosystems

The build-up of carbon dioxide and other greenhouse gases in the atmosphere is changing several of the features of the Earth's climate, oceans, coasts and freshwater ecosystems that affect fisheries and aquaculture, air and sea surface temperatures, rainfall, sea level, acidity of the ocean, wind patterns, and the intensity of tropical cyclones (Cochrane,et al. 2009).

Fishers, fish farmers and coastal inhabitants will bear the full force of these impacts through less stable livelihoods, changes in the availability and quality of fish for food, and rising risks to their health, safety and homes. Many fisheries-dependent communities already live a precarious and vulnerable existence because of poverty, lack of social services and essential infrastructure. The fragility of these communities is further undermined by overexploited fishery resources and degraded ecosystems. The implications of climate change for food security and livelihoods in small island states and many developing countries are profound.

Climate change is modifying the distribution and productivity of marine and freshwater species and is already affecting biological processes and altering food webs. The consequences for sustainability of aquatic ecosystems, fisheries and aquaculture, and the people that depend on them, are uncertain.

Rising ocean temperatures and ocean acidification means that the capacity of the ocean carbon sink will gradually get weaker giving rise to global concerns expressed in the Monaco (UNEP. 2009).

Of most concern in these anthropogenic factors is the increase in $CO2$ levels due to emissions from fossil fuel combustion, followed by aerosols (particulate matter in the atmosphere) and cement manufacture. Other factors, including land use, ozone depletion, animal agriculture and deforestation, are also of concern in the roles they play - both separately and in conjunction with other factors in affecting climate, microclimate, and measures of climate variables.

Understanding the way in which climate change may affect decadal and shorter time scale variability is therefore essential in predicting future climate impacts on marine ecosystems and fisheries. Climate change affect on the glaciers and the sea lea level.

**1. Glaciers:** Glaciers are among the most sensitive indicators of climate change advancing when climate cools (for example, during the period known as the Little Ice Age) and retreating when climate warms. Glaciers grow and shrink; both contributing to natural variability and amplifying externally forced changes.

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1- (AGW)

**2. Sea Level Change:** Global sea level change for much of the last century has generally been estimated using tide gauge measurements collated over long periods of time to give a long-term average.

### A. Adaptation and Mitigation

Adaptation, means considering in advance what changes may occur and taking those changes into account in short-term decision making and long-range planning. We do, however, suggest policy options concerning adaptation.

Mitigation in this context means reducing the rate of climate change, and is a politically difficult subject that has completely dominated public discourse on climate change.

Climate change (i.e. long-term shifts in temperature, wind fields, hydrological cycles etc) and climate variability (shorter term shifts on annual to decadal time scales) have occurred throughout history and natural systems have developed a capacity to adapt, which will help them to mitigate the impact of future changes. However two factors will limit this adaptive capacity in future. Fisheries and aquaculture need specific adaptation and mitigation measures that:

(I) The rate of future climate change is predicted to be more rapid than previous natural changes.

(II) The resilience of species and systems is being compromised by a number of concurrent pressures, including fishing, loss of genetic diversity, habitat destruction, pollution, introduced and invasive species and pathogens.

Report 2007 - Development and Climate Change shows that reducing overcapacity in fishing fleets and rebuilding fish stocks can both improve resilience to climate change and increase economic returns from marine capture fisheries by US$50 billion per year, while also reducing GHG emissions by fishing fleets. Consequently removal of subsidies on fuel for fishing can have a double benefit by reducing emissions and promoting overfishing (IPCC. 2007).

The oceans have removed 50% of the anthropogenic CO2, so the oceans have absorbed much of the impact of climate change. The famous White Cliffs of Dover illustrate how the ocean captures and buries carbon. These limestone cliffs are formed from the skeletons of marine plankton called coccoliths. Similarly, petroleum formation is attributed largely to marine and aquatic plankton further illustrating the key role of the oceans in carbon sequestration. The current level of GHG emissions means that ocean acidity will continue to increase and aquatic ecosystems will continue to degrade and change (Seiz, 2007).

Fisheries and aquaculture needs to be blended into national climate change adaptation strategies. Without careful planning, aquatic ecosystems, fisheries and aquaculture can potentially suffer as a result of adaptation measures applied by other sectors, such as increased use of dams and hydropower in catchments with high rainfall, construction of artificial coastal defenses or marine wind farms.

Mitigation solutions are not at all well known and require innovative approaches such as the recent inclusion of mangrove conservation. Other approaches to explore are linking vessel decommissioning with emissions reduction funding schemes, finding innovative but safe ways to sequester carbon in aquatic ecosystems, and developing low-carbon aquaculture production systems.

### B. Fisheries and Aquaculture in a Changing Climate

Rising ocean temperature sand ocean acidification is radically altering aquatic ecosystems. Climate change is modifying fish distribution and the productivity of marine and freshwater species. This has impacts on the sustainability of fisheries and aquaculture, on livelihoods of the communities that depend on fisheries, and on the ability of the oceans to capture and store carbon (biological pump). The effect of sea level rise means that coastal fishing communities are in the front line of climate change, while changing rainfall patterns and water use impact on inland (freshwater) fisheries and aquaculture (Harley 2006).

Fisheries and aquaculture contribute significantly to food security and livelihoods and depend on healthy aquatic ecosystems but these facts are often unrecognized and undervalued.

- Fish (including shellfish) provides essential nutrition for 3 billion people and at least 50% of animal protein and minerals to 400 million people from the poorest countries.
- Over 500 million people in developing countries depend, directly or indirectly, on fisheries and aquaculture for their livelihoods.
- Aquaculture is the world’s fastest growing food production system, growing at 7% annually.
- Fish products are among the most widely traded foods, with more than 37% [by volume] of world production traded internationally.

### C. Impact on Fish Production

The rising ocean acidity makes it more difficult for marine organisms such as shrimps, oysters or corals to form their shells a process known as calcification. Many important animals, such as zooplankton, that forms the base of the marine food chain have calcium shells. Thus the entire marine food web is being altered there are "cracks in the food chain".

### D. Impact on Fishing Communities

Coastal and fishing populations and countries dependent on fisheries are particularly vulnerable to climate change. Fishing communities in Bangladesh are subject not only to sea-level rise, but also flooding and increased typhoons. Fishing communities along the Mekong River produce over 1 million tons of basa fish annually and livelihoods and fish production will suffer from saltwater intrusion resulting from rising sea level and dams.

Best current projections of changes in global marine primary production, based on an ensemble of climate models show an increase of less than 10% by 2090, which seems a comfortably small change. However, the underlying models are highly uncertain and there are likely to be big regional differences (Sarmiento et al. 2005).

### E. Short-Term Effects of Climate Change on Fish Harvests

In the short term, the direct effects of climate change would occur as a result of changes in species abundance. Changes in species abundance may have a variety of direct and indirect economic and social effects. We may summarize potential effects of climate change on fish harvests as follows:

1) Climate change is likely to reduce the abundance of some species while increasing the abundance of others.
2) Changes in harvests. As the abundance of a species changes, fishermen will catch more or fewer fish either
3) Changes in fishing and processing employment. Changes in harvests affect employment opportunities in fish harvesting and processing.
4) Changes in prices. Fisheries markets are highly sensitive to supply. Changes in harvests tend to have opposite effects on prices,
5) Changes in fishing and processing income and profits. Changes in harvest volumes, prices and costs combine to affect income and profits earned in both fish harvesting and fish processing.
6) Changes in local and statewide tax revenues. Fisheries business taxes, aquaculture enhancement taxes, and fisheries marketing assessments are directly tied to the ex-vessel value of harvests.
7) Social stresses. Changes, particularly reductions, in income and employment may contribute to a wide variety of family and community stresses.
8) Political conflict. Changing relative harvest levels can upset the political balance in agreements over allocation of mixed-stock fisheries and transregional or transnational fisheries.

Changes in costs and opportunities due to changes in weather and ice conditions. Changes in the physical environment, such as weather and ice conditions, may affect where and when fishing is physically possible as well as the costs of fishing.

In the short term, to the extent that changes in harvests are not offset by changes in prices, the value of current harvest. Because changes in climate are likely to increase harvests of some species while reducing harvests of other species, it is unlikely that the relative magnitude of the change in total exvessel or wholesale value, as well as other economic effects, would be as great as the relative magnitude of the change in value for individual species.

## III. The Models Climate Change on Marine Ecosystems

### *A. Changes in Global Marine Primary Production*

Modeling is a necessary tool for assessing future impacts of climate change. A major comparative study Sarmiento simulated the effect of greenhouse gas emissions using six Atmosphere-Ocean General Circulation Models (AOGCMs) to examine which aspects of the models determine how ocean biology responds to climate. The study compared "realistic" emission scenarios for the period from pre-industrial to 2050 and 2090 with a control in which emissions remained at pre-industrial levels. The three groups of factors which govern the biological response are (Sarmiento et al. 2005):

- warming
- light supply, as determined by ice cover, cloudiness and surface mixed-layer thickness
- Altered nutrient supply due to changed vertical stability and exchange.

Predicted climate induced alterations in nutrient supply and production are predominantly negative, due to reduced vertical mixing. In high latitude regions the resultant increased stability of the water column will however have a positive effect on production, in spite of reduced nutrient supply, because phytoplankton will no longer be mixed down to depths greater than their compensation.

Primary production in the comparative modeling study was estimated using empirical models for a set of seven biomes (marginal sea ice; sub polar; subtropical seasonally stratified; subtropical permanently stratified; low latitude upwelling; tropical upwelling, tropical down welling), A small global increase in marine chlorophyll and primary production is predicted (<10%) for 2050 and 2090, compared with the preindustrial control scenario, but with quite big regional differences(Sarmiento et al., 2005).

Satellite observations of ocean chlorophyll indicate that global ocean annual primary production has declined by more than 6% since the early 1980s. Gregg study based on over 100 000 plankton samples collected between 1958 and 2002 with the Continuous Plankton Recorder (CPR) (Richardson, and Schoeman, 2004) showed an increase in phytoplankton abundance in the cooler regions of the NE Atlantic and a decrease in warmer regions (Gregg et al., 2003).

### *B. Changes in Fisheries Production*

Changes in primary and secondary production will obviously have a major effect on fisheries production. The comparative study Sarmiento, in which six different AOGCMs were used, indicates that production may increase by not more than 10% over the period to 2050, but the level of confidence in this estimate is low and the baseline for the comparison is the “pre-industrial” state (Brander 2005).

In contrast, observations from satellite and large scale plankton sampling show declines in phytoplankton and chlorophyll over the past 20-50 years, which are consistent with the expected consequences of reduced nutrient supply due to strengthening of vertical density gradients.

Qualitative changes in production may have major impacts on food chains leading to fish regardless of changes in the absolute level of primary production. Examples of this include the observed switch from krill to slap as the major nektonic species in parts of the Antarctic and the ascendance of gelatinous species to a dominant position in areas such as the Black Sea. In the former case climate change was probably a major factor, but in the latter it was not (Atkinson et al., 2004).

### *C. Changes in Fish Population Processes*

Global, regional and smaller scale impacts of climate change on biological production are ultimately the sum of processes which act on individual organisms. Each species has particular characteristics which govern their resilience and tolerance of changes in their environment.

The processes, whose response to environmental variability can be studied in exquisite detail, are growth, reproduction, mortality and behavior (to find food, avoid predators and maintain themselves in favorable locations throughout their life history).To these responses can be added species interactions and ecosystem processes.

### D. Changes in Fisheries on Human Societies

Fluctuations in fish stocks have had major economic consequences for human societies throughout history. The increase in distant water fleets during the last century reduced the dependence of that sector of the fishing industry on a particular area or species, but the resulting increase in rates of exploitation also reduced stock levels and increased their variability.

Fishing communities which were dependent on local resources of just a few species became more vulnerable to fluctuations in stocks, whether due to overfishing, climate or other causes.

Given the uncertainties over future marine production and consequences for fish stocks, it is not surprising that projections of impacts on human societies and economies are also uncertain.

Global aquaculture production increased by nearly 50% between 1997 and 2003, while capture production decreased by nearly 5% and the likelihood that these trends will continue also affects the way in which climate change will affect fisheries production.( Smith and Hitz.2003)

### E. Changes in Sea Level Rise

Two studies were investigated the effects of rising sea level: Fankhauser (1995) and Nicholls et al. (1999). We present results from the first two of these studies. Fankhauser produced estimates of direct cost in dollar terms. The direct cost method includes the cost of dry land and wetland loss, the costs of protection, and the loss of fixed capital. Nicholls et al. focused on the effects of sea level rise on people directly affected and adopted number of people at risk of coastal flooding as their measure. In general, The studies are consistent with this conclusion; more land will be inundated as sea level rises, damages from higher storm surges will mount, and costs will increase as coastal defenses are raised or lengthened to provide necessary additional protection.

It should also be noted that sea levels are expected to continue rising for centuries following any stabilization of global mean temperatures. For example, Church show that sea level would continue to rise in response to thermal expansion for two to three millennia beyond the time atmospheric CO2 concentrations are stabilized at a doubling or quadrupling above preindustrial CO2 levels. Sea level would eventually rise 0.5 to 2 m for a doubling of CO2 and 1 to 4 m for a quadrupling (Church et al. (2001).

### F. Changes in Marine Ecosystem Productivity

Bopp attempted to predict how climate change might affect marine primary production (production by marine plants, including phytoplankton and seaweeds). He considered a future of doubled CO2 and used the oceanic output (advection and eddy diffusion) from two different coupled atmosphere-ocean GCMs (LMD5 and Arpege). Their baseline climatology holds CO2 constant at 350 ppm, and the global warming scenario increases CO2 at 1% per year until reaching a doubling of CO2 after 70 years (they also consider a tripling and quadrupling of CO2 in a limited fashion, occurring at 110 and 140 years, respectively (Bopp et al. 2001).

Bopp et al. made several assumptions that bear noting. First, because their biogeochemical models were run off line, the analysis did not provide for feedback to the climate system from changes in the ocean's biochemistry. Second, the biogeochemical schemes they employed are grossly simplified in that they are phosphate based and lack limitation by other nutrients (e.g., Fe, N, and Si). Finally, the models they employed do not account for competition between different species of plankton or that species abundance may change because of climate induced changes in ocean circulation or mixing (Knapp1998).

In general, changes in production are driven by reduced nutrient supplies in the low latitudes and an increased light efficiency in the high latitudes due to a longer growing season. Simple summation of monetized impacts across regions or sectors would give the wealthy more weight than the poor. The use of people at risk or lives affected could overstate the true impacts because some people may be affected in more than one sector. This relationship is uncertain because there is only one study on this topic.

In summary, the literature shows that for increases in GMT between 0°C and 3 to 4°C, the relationship between impacts and temperature is uncertain. Beyond this point, the studies generally estimated net adverse impacts that increase as GMT increases.

## IV. Conclusion

Global warming in the 21st century could trigger fundamental and potentially catastrophic changes in the climate system that may not be realized until after the 21st century. These events might include a slowdown or complete breakdown of the thermohaline circulation, which could result in cooling of the North Atlantic, including Western Europe and eastern North America melting of the West Antarctic Ice Sheet; or a runaway greenhouse effect. The magnitudes of change required to trigger catastrophic events are uncertain.

Almost all of the studies we examined estimated that there will be increasing adverse impacts beyond an approximate 3 to 4°C increase in global mean temperature. The studies do not show a consistent relationship between impacts and global mean temperatures between 0 and 3 to 4°C. In coastal resources it is clear that impacts will be adverse with low levels of temperature change.

The goal for analysts continues to be laying out and assimilating information that improved management of fisheries and of marine ecosystems can undoubtedly play an important role in adapting to the impacts of climate change. Management advice must include complete and transparent information on risks and uncertainties which arise from data quality and from structural deficiencies in the assessment models.

Adaptation measures are well known by managers and decision makers, but political will and action is often lacking. To build resilience to the effects of climate change and derive sustainable benefits, fisheries and aquaculture managers needs to adopt and adhere to best practices such as those described in the FAO Code of Conduct for Responsible Fisheries. These practices need to be integrated more effectively with the management of river basins, watersheds and coastal zones.

Well-designed and reliable monitoring of fish stocks and the marine ecosystem is essential in order to detect changes and give advance warning of alterations in the productivity of individual species and of the structure and functioning of the ecosystems on which they depend.

Following suggestions are proposed for future management of fisheries:

1) Implement comprehensive and integrated ecosystem approaches to managing coast sand oceans, fisheries, aquaculture, disaster risk reduction and climate change adaptation.
2) Move to environmentally-friendly and fuel efficient fishing and aquaculture practices.
3) Eliminate subsidies that promote overfishing and excess fishing capacity.
4) Undertake vulnerability and risk assessments at the "local' level.
5) Integrate and "climate-proof" aquaculture with other sectors.
6) Explore carbon sequestration by aquatic ecosystems.
7) Respond to the opportunities and threats to food and livelihood security due to climate change impacts.

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