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The potential impact of climate change on fisheries and aquaculture in the Asian region

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Gayathri Sriskanthan and Simon Funge-Smith

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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For copies please write to:

The Senior Fishery Officer
FAO Regional Office for Asia and the Pacific
Maliwan Mansion, 39 Phra Athit Road
Bangkok 10200
THAILAND
Tel: (+66) 2 697 4000
Fax: (+66) 2 697 4445
E-mail: FAO-RAP@fao.org

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Foreword

The 31st Session of the Asia-Pacific Fishery Commission (APFIC), convened in Jeju, Republic of Korea in September 2010, emphasized that adaptation and mitigation of the impacts of climate change related to fisheries and aquaculture is an important challenge for the region. The session recommended that APFIC should review the effects of climate change on fisheries and aquaculture in the region and provide advice to member countries on strategic planning for adaptation and mitigation measures for the sector. This review was commissioned in support of the workshop *Implications of climate change on fisheries and aquaculture: challenges for adaptation and mitigation in the Asia-Pacific region,* which took place from 24 to 26 May 2010 in Kathmandu, Nepal organized by the Asia-Pacific Fishery Commission (APFIC) in collaboration with the Directorate of Fisheries Development of the Government of Nepal. Support for the workshop was provided by the Regional Fisheries Livelihoods Programme for South and Southeast Asia (RFLP) and the Bay of Bengal Large Marine Ecosystem Programme (BOBLME).

Fisheries and aquaculture in Asia provide considerable trade, employment and food security and some of the densest rural populations of the world are found on coastlines and floodplains of the region. Impacts from climate change such as increasing ocean acidification, shifting fish distributions and more frequent cyclones may increase the negative impacts on capture fisheries which are already at their limits through over exploitation, coastal degradation and pollution. Productivity and viability in aquaculture operations are also expected to be negatively impacted by factors including higher sea water levels, flooding, increased competition for water resources and disease occurrence patterns.

Climate change is expected to contribute to increasing disruptions to aquatic and coastal systems upon which many millions of Asian people depend and it is vital that governments in the region understand the risks, identify vulnerable systems and develop adaptive strategies. Increased policy attention and financial resources for climate change adaptation and mitigation in the fisheries/aquaculture sector are urgently needed; and the marine fishery and aquaculture sectors need to be closely integrated into national climate change policies. It is therefore essential that the interactions between capture fisheries and aquaculture, along with other sectors such as agriculture and disaster management are integrated into the policy planning processes.

Despite the increasing global attention on climate change and projections of their likely effects, there remain serious gaps in coverage relating to the tropical regions of Asia and particularly the fishery and aquaculture sectors. This greatly constrains dialogues and effective planning for these important sectors in the region. This regional review is intended to provide a preliminary insight into the current state of knowledge and indicate some likely implications for the region.

Hiroyuki Konuma
Assistant Director-General and
Regional Representative for Asia and the Pacific

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Introduction

The Asian region is currently home to 87 percent of all people involved globally in fisheries and aquaculture, and this sector contributes significantly to the national GDPs of many countries in Asia (FAO 2008a). Furthermore, the sector plays a significant role in food security and between 15 to 54 percent of the annual protein intake in the region comes from fisheries and aquaculture products (Silvestre *et al.* 2003). However, existing marine and inland capture fisheries stocks are threatened by overexploitation and poor management; 75 percent of global fish stocks are fully exploited, overexploited, depleted or recovering (World Bank and FAO 2008). Studies estimate that the biomasses of coastal fishery resources in South and Southeast Asia are between 5 to 30 percent of their pre-fisheries expansion levels (Silvestre *et al.* 2003). The aquaculture industry is rapidly filling this vacuum and currently produces just under half the world's fishery products. Asia's stake in this industry is disproportionately high; the region's share of aquaculture production, when taking into account aquatic plant production, is about 90 percent in volume and 80 percent in value (FAO 2008a) and close to 65 percent of aquaculture production is situated in inland areas, concentrated mostly in the tropical and subtropical regions of Asia (De Silva and Soto 2009).

Any adverse impacts to the fisheries sector in Asia will therefore have implications for the region's economic development, for poverty reduction, and for global as well as regional food security.

There is now a considerable, credible body of evidence that human induced climate change is occurring, leading to changes in the earth's fundamental physical, chemical and biological processes (IPCC 2007a, Meehl *et al.* 2007); current thinking on climate change science and predicted global trends are introduced and summarized in the following section. Records indicate that surface air and sea temperatures have increased because of human induced changes to the atmosphere (mainly associated with the emission of greenhouse gases) and that the rate of warming has accelerated in the last few decades. The future scale of this change will depend on what course of action the governments of the world take to reduce emissions over the coming decades. Even within a range of scenarios, from a scenario of strong, immediate action to one of business as usual, climate change is already happening and having an impact on natural systems. The magnitude and impact of this change is the only thing that we may be able to influence, if we are able to alter our patterns of development.

> **The impacts of climate change are likely to be far from uniform and it is expected that the Asian region will face very specific and locally variable challenges.**

The impacts of climate change are likely to be far from uniform and it is expected that the Asian region will face very specific and locally variable challenges. Certain trends and impacts may be more pronounced in Asia (e.g. temperature increases are likely to be above the global norm in many parts of the region; a number of important river basins in Asia are threatened by further water stress; people in the region are likely to be disproportionately impacted by flooding; biodiversity loss will be greater in the tropics).

Importantly, it must be recognized that Asia is highly vulnerable to climate change because of the low capacity of many countries in the region to respond and adapt; many countries cannot cope with current levels of climatic variability and extreme events, indicating that existing systems would be overwhelmed (Preston *et al.* 2006). As a region that is still beset with poverty and low levels of development, it is likely that only sudden, disaster-related climate change related issues will be addressed (Michel and Pandya 2010). There is a possibility that slower processes, such as rising sea levels and gradual shifts in agricultural and fisheries related production systems may be ignored, even if planning ahead for these changes will ultimately increase the chances of coping with negative impacts.

Certain fundamental questions on the future ability of the fisheries sector to provide jobs, contribute to national economies and provide food security in a climate change affected future currently remain unanswered. In the absence of any strategic intervention the world's population is projected to reach 9 billion by 2050; the majority of this population growth will occur in Asia.

- How will food security be met for an increasing number of people given all of the above challenges?
- How will the fisheries sector fit into a climate change altered socio-economic landscape (e.g. given an altered agricultural base and freshwater availability) in Asia in the near and distant future?
- How should Asian nations take steps to mitigate impacts to the sector as well as adapt to inevitable changes?

As a sector highly dependent on natural resources and with a high sensitivity to environmental variables, the potential impact of climate change on the fisheries sector should be of great concern to policy-makers in the region. Climate change is likely to have further negative impacts on capture fisheries systems already stressed by overexploitation and pollution. It is also likely to impact the productivity and viability of aquaculture operations across the region. Climate change will have profound consequences on related sectors such as agriculture, water management and coastal development, which will have associated influences on the fisheries sector.

Understanding the challenges and opportunities that climate change will pose to the fisheries sector in the Asian region will be crucial if governments hope to minimize negative impacts and buffer the impacts of climate change on some of the most vulnerable sections of society that are dependent on this sector. This document examines the significance of climate change for the fisheries sector in Asia and reviews what steps could be taken to minimize negative impacts as well as capitalize on potential opportunities. Drawing from the available literature some conclusions are drawn regarding the:

- impact of climate change on Asia;
- implications of this to the fisheries sector in Asia;
- significance of these findings to policy makers; and
- kind of action that should be taken to respond to potential challenges and opportunities.

An overview of climate change

This section provides a very brief overview of current theories on anthropogenic climate change.[1]

An ever-shifting climate

The earth's climate has oscillated greatly through the millennia. During the time of the dinosaurs (252 to 65 million years ago) the earth was significantly warmer than it is today, however, just 20 000 years ago a glacial climate prevailed with much of North America and Scandinavia covered in ice sheets. Other than warming on geologically significant timescales of thousands and millions of years, there has also been natural warming in certain areas within the last few centuries. For instance, Europe experienced a period of relative warmth between the 10th and 13th century and relative cold from the 15th to the 19th century. How does the current and predicted warming that is connected to human activity differ from this? Variations in the near past, such as the European warming and then cooling, are thought to be caused by natural factors, such as volcanic eruptions and changes in solar output rather than human activity. Furthermore, these more recent changes were confined to specific regions. Current increases in temperature are global, with every region on the planet experiencing warming and current levels of warming appear to exceed these near-recent precedents.

The importance of carbon dioxide (CO_2) in past global temperature changes

Geological studies reveal that the earth's climate has varied widely over the last few hundred million years and these changes appear to have been accompanied by clear changes in atmospheric CO_2 levels. A general positive correlation between warm climates and high CO_2 levels can be deduced from the geological record. However, this correlation is not perfect, indicating that other factors (e.g. the growth of polar ice sheets that act as reflective surfaces, providing extra cooling and negating the impact of increased atmospheric CO_2) have also been important in determining climate.

The climate is currently changing

As records of surface air temperatures have been recorded over much of the world over the last 150 years, it is possible to calculate global averages. These records indicate that surface air and sea temperatures have increased and that the rate of warming has accelerated in the last few decades. The rate of warming during the twentieth century was less than 0.1ºC per decade; this has almost doubled to about 0.2ºC per decade. The average temperature of the world has increased from 13.5ºC to 14.5ºC since the beginning of the twentieth century.[2]

> **"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."**
>
> **IPCC (2007a)**

Human activity is contributing to this change

The earth's climate can change as a result of natural variability associated with changes in energy from the sun, volcanic eruptions, or natural cycles such as El Niño. However, through analysing the possible impacts of these natural factors and comparing the actual observed changes in the climate, it is possible to obtain an indication of how much human activity is contributing to climate change.

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[1] Unless otherwise stated, the material for this introductory section is taken entirely from the comprehensive guide to climate change developed by Mann and Kump (2008). As an authoritative summary of climate change science and the findings of the IPCC, it was felt that this provided the best, comprehensive scientific introduction to climate change for the purpose of this paper.

[2] Note: The rise in average temperatures cannot be attributed to the increased energy utilization that accompanies urbanization as (a) calculations are made adjusting for potential urban bias; and (b) the same pattern is observed even if only rural areas are taken into consideration.

There is a firm body of evidence that indicates that the current rate of climate change is mainly a result of human activities. The IPCC's fourth assessment report in 2007 concluded that anthropogenic warming has been significant in every continent except for Antarctica (IPCC 2007a). These findings have been corroborated by other research agencies, made possible by recent advances in the quality of observational data and through the application of improved analytical techniques. A recent study carried out by the UK Government's Meteorological Office reviewing numerous studies examining anthropogenic climate change concluded that there was a high level of certainty that the influence of human activity is responsible for observed changes in the earth's climate. This review also noted that changes in Antarctica may also be caused by anthropogenic warming, updating the IPCC findings (Stott *et al.* 2010).

> **"… there is an increasingly remote possibility that climate change is dominated by natural rather than anthropogenic factors."**
>
> **Stott *et al.* (2010)**

The main way that humans have an impact on the climate is through increasing the atmospheric concentrations of greenhouse gases, leading to the warming of the lower atmosphere. Greenhouse gases refer to gases that absorb heat, warming the atmosphere around them; most atmospheric gases (e.g. nitrogen and oxygen) do not have this propensity and are not greenhouse gases. Greenhouse gases include CO_2, water vapour and methane. Without these absorbing some heat the earth's temperature would fall below zero. However, increasing the concentration of greenhouse gases in the atmosphere will lead to a corresponding increase in this warming effect.

The most significant greenhouse gas being released into the atmosphere as a result of human activity is CO_2. This has always been released into the atmosphere by natural processes, but fossil fuel burning and deforestation represent new sources of atmospheric CO_2 that have resulted in a continuous rise in CO_2 levels over the last 200 years. Even if we halted the burning of fossil fuels today it would take several centuries for CO_2 levels to reach their pre-industrial levels. Methane is another important compound that contributes to the greenhouse effect. An increase in agricultural production, particularly rice cultivation and livestock production has resulted in an increase in atmospheric levels of methane. Nitrous oxide (N_2O) is another significant greenhouse gas that is released from a variety of human activities (e.g. application of nitrogen fertilizer, deforestation and the burning of fossil fuels) that have resulted in a 40 to 50 percent increase in the flow of N_2O into the atmosphere.

Current measurements of atmospheric CO_2 are 386 parts per million (ppm). If all existing fossil fuel resources are used without any mitigating measures to absorb the CO_2 released through consumptive activity, atmospheric CO_2 levels could rise above 2 000 ppm – this exceeds anything experienced in over 50 million years. The internationally recognized authority on climate change, the Inter-governmental Panel on Climate Change (IPCC), in their 2007 policy recommendations for dealing with global climate change recommended a safe maximum of 450 ppm (IPCC 2007a). However, there is a growing scientific consensus that 350 ppm should be the revised maximum threshold[3] and that achieving this target would provide humanity with a better chance of circumventing more catastrophic global changes. It has been suggested that the 350 ppm target could partly be achieved by phasing out coal use and adopting agricultural and forestry practices that sequester carbon (Hansen *et al.* 2008).

The role of feedback mechanisms

In addition to increased CO_2 leading to greater warming, the very impact of initial warming will have knock on implications for the warming cycle resulting in a number of positive feedbacks (i.e. further increases in warming) and negative feedbacks (i.e. decreases in warming). One of the impacts that warming will have is to reduce the capacity of natural mechanisms to remove carbon from the

[3] A number of eminent scientists are calling for a revision of the maximum to 350 ppm, including the eminent climate scientist James E. Hansen, Rajendra Pachauri, the UN's "top climate scientist" and Head of the IPCC, Jonathan Foley, the Director of the University of Minnesota's Institute on the Environment, Peter H. Gleick, President of the Pacific Institute and Adele C. Morris, the Policy Director of the Brookings Institution's Climate and Energy Economics Project.

atmosphere. It is expected that the positive feedbacks will outweigh the negative feedbacks. In addition to this, future climate change will reduce the efficiency of the Earth system (land and ocean) to absorb anthropogenic CO_2; this positive feedback may result in additional atmospheric CO_2 of concentrations varying between 20 and 220 ppm (depending on the projected scenario) by 2100 (Meehl *et al.* 2007). Both these factors mean that there will be a more rapid build-up of CO_2 and a warmer climate. Examples of these are listed in table 1.

Table 1 Positive and negative feedbacks that might contribute to global warming

Examples of positive feedbacks
– An initial increase in warming because CO_2 release will lead to increased surface water evaporation, leading to the release of water vapour which is itself a greenhouse gas that will contribute to the positive feedback. – The melting of heat reflective white snow and ice because of increased warming will also lead to the exposure of darker, more heat absorptive surfaces (e.g. soil, rocks, ocean water) contributing to increased rates of heating. – Soil microbes increase their growth and respiration rates at warmer temperatures. CO_2 is one of the waste products of their metabolism and carbon in soils is now being converted into CO_2 at increasing rates. – Warmer oceans have less ability to absorb atmospheric CO_2. – Slowing of ocean circulation because of warming reduces the mixing of nutrients at the ocean's surface, slowing productivity and weakening the action of the pumping of CO_2 from surface waters that would allow the ocean to absorb more atmospheric CO_2. – Calcium carbonate acts as a ballast carrying the decaying tissue of organisms to greater depths and removing carbon from the surface waters. Acidification will reduce calcification and this ballast effect. – The production of calcium carbonate (e.g. through calcification by corals and certain plankton) results in the release of CO_2 in the water, reducing the ability of the ocean to absorb atmospheric CO_2. Acidification of the surface ocean reduces the rates of calcification by such organisms. Furthermore, it is predicted that certain calcifying organisms will become extinct this century.
Examples of negative feedbacks
– Rock weathering (i.e. the process that converts rock into soil) will be stimulated by increased temperatures and rainfall. Atmospheric CO_2 dissolved in rain forms carbonic acid, speeding up the weathering process and removing CO_2 from the atmosphere. – The evaporation of water because of increased warming may lead to the development of low clouds that could contribute to cooling the atmosphere.

The above descriptions of potential positive and negative feedback loops illustrate the fact that the relationship between greenhouse gas emissions and rates of warming is not a simple linear one and is also dependent on biological processes.

Projecting changes

As the climate is governed by a complex interaction of physical, biological and chemical processes, developing models to predict future changes confidently is extremely challenging. Current models are very sophisticated and closely reproduce past as well as future changes and provide predictions that should be taken seriously. However, projections can be presented in the form of scenarios that could be expected given a range of potential circumstances. For instance, it is difficult to say what kind of changes will be made in patterns of human consumption of fossil fuels and land use practices over the next few decades and centuries. Climate researchers have therefore developed different projections of future scenarios based on a range of important variables, such as regional differences in per-capita income, rates of economic growth, rates of development and adoption of new energy technologies, and the rate of population growth or decline.

Main global impacts of climate change

It is now generally accepted that warming of the climate system is unequivocal, as evidenced from global increases in: average air and ocean temperatures; melting of snow and ice; and average sea levels. The IPCC notes that, "At continental, regional and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones." (IPCC 2007a). The continued emission of greenhouse gases at or above current rates will cause changes in the global climate system during the twenty-first century that are very likely (i.e. 90 to 99 percent probability) to be larger than those observed during the 20th century (Meehl *et al*. 2007).

Some general global trends, taken from IPCC (2007a) and Meehl *et al*. (2007), are as follows:

- The linear warming trend over the last 50 years was 0.13ºC (between 0.10ºC to 0.16ºC) per decade, which is nearly twice the rate of warming for the last 100 years.
- There will be warming of about 0.2ºC per decade for the next two decades.
- According to different projected scenarios, the temperature change in the decade of 2090 to 2099 could range from +0.3ºC to as high as +6.4ºC compared to 1980-1999 levels.[4]
- The global average sea level rose at an average rate of 1.8 mm (between 1.3 to 2.3 mm) per year over 1961 to 2003.
- According to different projected scenarios, the temperature change in the decade of 2090 to 2099 could range from 0.18 m to as high as 0.59 m compared to 1980 to 1999 levels.
- Globally averaged mean water vapour, evaporation and precipitation are projected to increase.
- An increase in the intensity of precipitation events will be particularly significant in tropical and high latitude areas that are also more likely to experience increases in mean precipitation – an increase in precipitation is projected for the Asian monsoon (along with an increase in inter-annual season-averaged precipitation variability).
- Sea level pressure is projected to increase over the subtropics and mid-latitudes, and decrease over high latitudes (by the order of several millibars by the end of the twenty-first century).
- There is a tendency for drying of the mid-continental areas during summer, indicating a greater risk of droughts in those regions.
- Increased CO_2 levels in the atmosphere will lead to increased acidification of the surface ocean.

[4] Lower ranges (+0.3ºC to +0.9ºC) are based on the scenario that concentrations of GHGs and aerosols do not exceed 2000 levels.

The impact of climate change on fisheries and aquaculture production systems

Fisheries systems in Asia are already overstressed because of poor management (e.g. overfishing, pollution, water abstraction, habitat alteration) and, because of this, may have a reduced capacity to recover from the additional stressors that climate change will present. Furthermore, key characteristics of the region, including high population growth rates, high levels of poverty, lack of awareness of climate risks, and unplanned urbanization, make many countries more susceptible to climate change induced changes and extreme events (Islam *et al.* 2010). Any observed changes in fisheries systems may therefore be a result of complex interactions between direct anthropogenic impacts and climate change related impacts. For instance, increases in water temperature, precipitation intensity and flow times are likely to exacerbate different forms of water pollution, amplifying these negative impacts (Kundzewicz *et al.* 2007). Any attempts to mitigate impacts or adapt fisheries systems in response to climate change therefore require a more holistic understanding of important variables at the site-level when planning for adaptation.

Despite this inherent complexity, climate change will have a number of fundamental impacts on systems that can be anticipated with relative certainty. A number of changes to basic physical parameters, such as water temperature and associated changes in water chemistry (e.g. pH) will potentially exert an impact on biotic systems as well as the specific physiology of certain species. Dramatic changes to hydrological cycles, freshwater flow regimes, and patterns of habitat alteration will present opportunities and challenges for different species and types of fisheries. Projections that have been carried out for fisheries systems provide some indication of the potential patterns of change that could be expected. These are not accurate predictions that account for the interaction of climate change related impacts with other environmental and socio-economic drivers relevant to the fisheries industry, but they do provide a strong indication of the issues that may be faced. The sections below review some of the more important drivers and trends of relevance to the fisheries sector in Asia. These are also summarized in table 2.

Direct biophysical and ecological consequences of projected changes

Projected changes to physical parameters and hydrological systems have profound implications for marine, coastal and freshwater systems. The IPCC states that substantial changes in the structure and functioning of both terrestrial and marine ecosystems are very likely to occur with a mean global warming of more than 2ºC to 3ºC above pre-industrial levels and the associated increased atmospheric CO_2 levels (Fischlin *et al.* 2007).

Increases in the intensity or frequency of extreme weather events are likely to result in increased flooding of coastal and inland areas, and sea level rise will result in the loss of coastal land, including important habitats such as mangroves (Cruz *et al.* 2007).

Changes in precipitation and drought patterns will impact water flow rates, which in turn will impact the migration and recruitment patterns of species and salinity levels in coastal areas (Barange and Perry 2009, Ficke *et al.* 2005, WorldFish 2007). Often, freshwater species are adapted to local hydrological patterns and drastic changes to these can have a huge impact on species survival and recruitment (Ficke *et al.* 2005).

Temperature driven changes in oceanic stratification and upwellings may lead to corresponding changes in productivity and nutrient availability. It is possible that middle and higher latitudes may potentially experience increases in productivity, however, it is currently uncertain how climate change will influence net primary productions at the global and regional scales, and the specific direction of the effect (increasing or decreasing) that climate change will have on upwelling systems, particularly coastal wind-driven systems. This, in effect, leaves us with little understanding of how climate change is likely to impact highly productive regions supporting valuable fisheries (Barange and Perry 2009).

Table 2 How climate change could directly affect the fisheries sector

Driver – Changes in sea surface temperature		
Biophysical effects	**Implications for fisheries**	**Implications for aquaculture**
– Less dissolved oxygen.		– Increased aeration cost, reduction in stocking densities.
– Increased incidence of disease and parasites.	– Changing susceptibility of some stocks to disease.	– Aquatic diseases may become more easily transmitted through aquaculture or fish introductions and movements (especially during CC adaptation activities).
– Altered local ecosystems with changes in competitors, predators and invasive species and changes in plankton composition.	– Impacts on the abundance and species composition of capture fisheries stocks. – Food webs impacted.	– Changes in infrastructure and operating costs from worsened infestations of fouling organisms, pests, nuisance species and/or predators. – Increased infrastructure and operating costs from worsened infestations of fouling organisms.
– Change in the location and area of suitable range for particular species.	– Increase in productivity of some fisheries/species: longer growing seasons and lower natural mortality in winter; enhanced metabolic and growth rates. – Movement of fishing operations to follow fish. – Potential species loss and altered species composition.	– Potential for increased production and profit in certain localities, especially for aquaculture. – Extension of range of warmwater species. – Increased costs or loss of performance for species at limit of their tolerance. – Impacts on wild seed availability (e.g. shellfish) for aquaculture: • change in spawning habitats/spawning time/seed availability. – Indirect impact because of availability of fish meal for aquaculture (pelagic species shifts).
– Enhanced primary productivity.	– Potential benefits for fisheries but perhaps offset by changed species composition; increased harmful algal blooms.	– Potential benefits for aquaculture perhaps offset by eutrophication/dissolved oxygen risks.
– Changes in timing and success of migrations, spawning and peak abundance, as well as in sex ratios.	– Potential loss of species or shift in composition in capture fisheries. – Potential for mitigation through culture-based or enhanced fisheries.	– Impacts on seed availability for aquaculture. – Potential opportunities from hatchery produced larvae for aquaculture.
– Damage to coral reefs that serve as breeding habitats and may help protect the shore from wave action.	– Reduced recruitment of fishery species. – Worsened wave damage to infrastructure or flooding from storm surges.	– Worsened wave damage on cage and line culture. – Impacts on coastal pond infrastructure; flooding from storm surges.

Table 2 *(continued)*

Driver – Rising sea level		
Biophysical effects	**Implications for fisheries**	**Implications for aquaculture**
– Loss of land.	– Loss of freshwater fisheries.	– Reduced area available for aquaculture.
– Changes to estuary systems.	– Loss of nursery grounds for coastal fisheries.	– Shifts in species abundance, distribution and composition of fish stocks and aquaculture seed.
– Saline intrusion.	– Impact on freshwater capture fisheries species composition.	– Reduced freshwater availability for aquaculture. – Opportunity to shift to brackishwater species. – Increased opportunities for mariculture.
– Changing coastal ecosystems: • mudflats and mangrove forests; • in some areas mangroves/wetlands may increase through flooding of inland areas.	– Reduced recruitment and stocks for capture fisheries. – Worsened exposure of fishing households and infrastructure to waves and storm surges.	– Reduced recruitment and stocks for broodstock and seed for aquaculture. – Worsened exposure to waves and storm surges and risk that inland/delta aquaculture will become inundated.

Driver – Ocean acidification		
Biophysical effects	**Implications for fisheries**	**Implications for aquaculture**
– Reduced capacity of the ocean to buffer climate change. – Rate of acidity change faster than any on record.	– Changes in species growth, reproduction and behaviour. – Affecting formation and dissolution of calcium carbonate shells and skeletons. – Impacts on marine ecosystems and the benefits they provide.	

Table 2 *(continued)*

Driver – Changes in precipitation and water availability		
Biophysical effects	**Implications for fisheries**	**Implications for aquaculture**
– Changes in fish migration, recruitment patterns, and recruitment success.	– Altered abundance and composition of wild stock. – Food webs impacted.	– Impacts on seed availability for aquaculture.
– Temperature/dry period changes: • dry periods/water scarcity; • altered and reduced freshwater supplies with greater risk of drought.	– Increased competition/conflict with other water users (especially for sustaining river flows). – Water quality changes because of population pressures, reduced flow or increased urban/agricultural discharges. – Mitigation through: • improvement or establishment of dry season refuges for floodplains; • establishing habitats; • engineer water management for the accommodation of fisheries or integration of refuges in water management systems.	– Lower water availability for aquaculture: • lower water quality causing more disease; • increased competition/conflict with other water users; • impacts on traditional systems, e.g. rice-fish farming; • higher costs of maintaining pond water levels; • reduced production capacity stock losses. – Change of culture species and culture systems (including some potential opportunities). – Aquaculture development may be an adaptation option or alternative form of livelihood, e.g. rice farmers.
– Changes in lake and river levels and the overall extent and movement patterns of surface water.	– Changes in food webs and species composition and decreased biodiversity in all inland aquatic environments: • altered distribution, composition and abundance of fish stocks; • fishers forced to migrate more and expend more effort; • habitat & nursing grounds change. – Requires increase dialogue with other sectors – do not block migration, sustain flows in rivers, maintain connectivity. – Possibility of mitigation through fishery enhancement.	– Performance of cage operations in rivers/waterbodies negatively affected.
– Sudden, high precipitation leads to rapid runoff. – Local flooding in deltas, coastal areas. – Rapidly changing water levels/ flow rates in rivers. – Flooding of low lying plains/ floodplains. – Glacial lake outbursts.	– Flooding, especially flash flooding: • flash flooding impacts to housing/communities; • migration following flooding; • major impacts in high dependent freshwater fisheries e.g. Tonle sap, Mekong, Ayerwaddy delta, Hilsa fisheries in Bangladesh; • turbidity and fluctuating water quality with consequent effect on fish stocks; • fishing gears damaged or lost. – Possible benefits for increased recruitment if flooding sustained long enough.	– Flash flooding impacts to housing/communities. – Dam discharges to ease pressure after heavy rain. – Flooding in areas where there is no preparedness: • aquaculture ponds flood; • cage aquaculture disturbed/damaged; • escape of stock. – Fluctuations in salinity temperatures, turbidity: • increased stress and disease; • impacts on seaweed culture (e.g. "Ice" disease).

Table 2 *(continued)*

Driver – Higher inland water temperatures		
Biophysical effects	**Implications for fisheries**	**Implications for aquaculture**
– Potential for enhanced primary productivity.	– Higher fishery production. – Eutrophication.	– Eutrophication, weed/fouling growth.
– Increased stratification and reduced mixing of water in lakes, reducing primary productivity and ultimately food supplies for fish species.	– Reductions in fish biomass. – Change in food webs and species composition.	– Dissolved oxygen problems and impacts of "turnover" affecting cage culture.
– Reduced water quality, especially in terms of dissolved oxygen; oxygen carrying capacity of water declines.	– Possible enhanced fish stocks for capture fisheries or, alternatively, reduced growth where the food and oxygen supply does not increase sufficiently in line with temperature.	– Reduced oxygen carrying capacity affects stocking densities/ production. – Possible reductions in feeding rates and growth. – Higher capital costs for aeration equipment or deeper ponds. – Increased aeration operational costs.
– Metabolic rates increased.	– Potential loss of species and alteration of species composition for capture fisheries. – Many species in tropical countries are already living at the upper end of their temperature tolerances and therefore may not be able to adapt to even higher temperatures.	– Possible benefits for aquaculture, especially intensive and semi-intensive pond systems: • raised metabolic rates, increased feeding rates and growth; • only if water quality, dissolved oxygen levels, and food supply are adequate. – Potential negative impacts on hatchery and nursery rearing operations or additional costs to mitigate.
– Changes in the range and abundance of pathogens, predators and competitors and invasive species introduced.	– Altered capture fisheries stocks and species composition.	– New diseases/patterns of epidemiology and possibly worsened losses to disease (and so higher operating costs) – May require changes of culture species.
– Changes in timing and success of migrations, spawning and peak abundance. – Impacts on natural populations that in turn have impact on aquaculture.	– Potential loss of species or shift in composition for inland capture fisheries: • species shifting with temperature; • migration timings patterns affected; • gonadal development/maturation/sex ratios change; • spawning times changing.	– Impacts on wild seed availability for aquaculture: • change in spawning habitats/spawning time/seed availability; • spawning period protracted; • maturation of hatchery brood fish affected.

Table 2 *(continued)*

Driver – Increase in frequency and/or intensity of storms		
Biophysical effects	**Implications for fisheries**	**Implications for aquaculture**
– Large waves and storm surges. – Inland flooding from intense precipitation. – Salinity changes.	– Impacts on wild fish recruitment and stocks. – Higher direct risk to fishers and loss of fishing gears. – Capital costs increased for moorings jetties, etc. that can withstand storms. – Increased insurance costs.	– Infrastructure damage or loss of aquaculture facilities: • mortality of loss of aquaculture stock; • biosecurity from escapees; • introduction of disease or predators into aquaculture facilities during flooding episodes; • extreme fluctuations in culture environment. – Capital costs increased in design cage moorings, pond walls. – Increased insurance costs.
– Lower water quality and availability for aquaculture; salinity changes.		– Loss of cultured stock; increased production costs; loss of opportunity as production is limited.
– Changes in lake water levels and river flows.	– Reduced wild fish stocks; intensified competition for fishing areas and more migration by fisher folk.	– Cage operations in rivers/water bodies affected.

Driver – Changes in El Niño-Southern Oscillation (ENSO)		
Biophysical effects	**Implications for fisheries**	**Implications for aquaculture**
– Changed location and timing of ocean currents and upwelling alters nutrient supply in surface waters and consequently primary productivity.	– Changes in the distribution and productivity of open sea fisheries.	– May impact productivity of some mariculture locations.
– Changed ocean temperature and bleached coral.	– Reduced productivity of reef fisheries.	
– Altered rainfall patterns bring flood and drought.	– See impacts for precipitation trends, drought and flooding above.	– See impacts for precipitation trends, drought and flooding above.

Source: Adapted from Badjeck *et al.* 2009 and WorldFish 2007, with information from the APFIC regional consultative workshops.

Such changes in basic parameters are likely to disadvantage species with narrow optimal ranges, opening up habitats for other species more suited to new niches that are likely to develop (Ficke *et al.* 2005). Changes in surface water temperatures may lead to a string of different direct impacts, including: less habitable environments as a result of decreases in dissolved oxygen; increases in algal blooms and parasites; direct changes to species (including growth patterns, spawning and migration times, and sex ratios); and damage to supporting ecosystems (Ficke *et al.* 2005, WorldFish 2007). It is predicted with high certainty that at "rapid" time scales (i.e. within a few years), temperature increases will result in reduced oxygen transport to tissues at higher temperatures, having an overall negative impact on the physiology of most fish species (Barange and Perry 2009).

Risk analyses indicate that 30 percent of coral reefs in Asia are likely to be lost within the next 30 years (Cruz *et al.* 2007). The loss of wetland ecosystems, such as mangroves and salt marshes, will result in the removal of important nursery and breeding grounds for many freshwater and marine species (WorldFish 2007). Coral reef systems are likely to be affected strongly by climate change because of their high sensitivity to sea surface temperatures, the potential for increased coral bleaching and the loss of coral habitats. As the surface waters of the oceans absorb increasing amounts of atmospheric carbon dioxide, there will be a corresponding decrease in the pH of these waters. This acidification effect is likely to reduce the ability of calcifying organisms, such as corals, to produce calcium carbonate calcification. The combination of sea surface warming and progressive acidification, compounded by the significant direct anthropogenic stresses on coral reefs, is likely to have a profound impact on coral habitats (Munday *et al.* 2008). What is very much unknown is the potentially large-scale impacts that the interaction between increasing temperatures and increasing acidification will have on marine systems (Barange and Perry 2009). It should be noted that there may be some positive benefits to habitat shifts in some instances – coastal areas in Asia that are likely to experience greater flooding may see an increase in available habitat for brackish water species (Cruz *et al.* 2007).

Direct impact on species composition and distribution

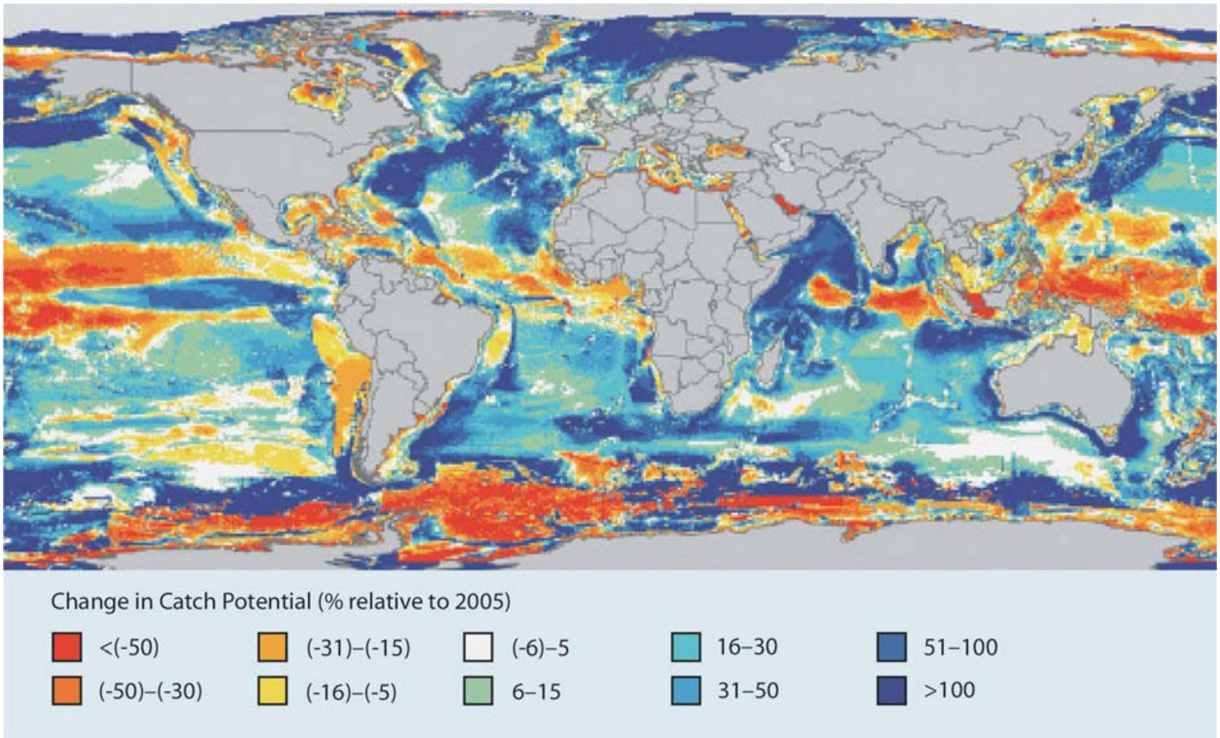
Marine and freshwater systems have experienced warm conditions in the past and have responded with changes in species composition and distribution; similar patterns are likely to be observed in response to anthropogenic global warming (Barange and Perry 2009). It is expected that climate change will result in a general poleward shift of both marine and terrestrial species. In marine systems, environmental factors are known to determine patterns of species richness, particularly of fish and invertebrates. *Benthic and demersal species in tropical and subtropical regions are likely to shift their distributions southwards*, potentially accompanied by a *decline in abundance. Pelagic species will also exhibit a southward shift,* however, some species *(e.g. anchovies) may benefit* from increased local wind-driven upwelling (Barange and Perry 2009). Projections carried out by Cheung *et al.* (2009a) suggest that changes to ocean environments may result in up to a 60 percent turnover in species composition by 2050. These projections also note that there may be poleward shifts in species, with a greater number of local extinctions in tropical areas.

The indications are that the *Asian region is likely to suffer a high loss of species.* It is also thought that the most rapid changes will be seen in mobile pelagic species that will respond by moving polewards. However, demersal species have also made latitudinal shifts as well as moving vertically to deeper depths or seeking colder upwellings (Cochrane *et al.* 2009, Barange and Perry 2009). Vertical stratification of the oceanic water column is predicted to increase as a result of climate change. This is likely to decrease productivity as a result of reduced mixing and nutrient supply and favour pelagic species over benthic species (Barange and Perry 2009).

Direct impact on catch potential

In line with shifts in species composition and habitat loss, global catch potential may see a significant geographical shift as a result of climatic changes that will have knock-on impacts on key variables that determine the productivity of fisheries systems (e.g. planktonic productivity in response to thermal change). In a projection exercise examining the global catch potential of 1 066 marine species during the period between 2005 and 2055, Cheung *et al.* (2009b) noted that if *greenhouse gas concentrations are doubled by 2100 there could be huge latitudinal shifts in catch, with the tropical countries in Asia* and elsewhere suffering up to a 40 percent drop in catch potential and high-latitude regions enjoying as much as a 30 to 70 percent increase in catch potential (see figure 1). Productivity will also be impacted by changes in overall biomass, as influenced by recruitment rates and growth rates, as well as being influenced by the availability of food (Barange and Perry 2009, Ficke *et al.* 2005, WorldFish 2007). Reactions can be complex, for instance changes in the species composition of plankton assemblages in response to climate change will have an impact on the nutritional value of food sources.

Figure 1 Change in maximum marine catch potential from 2005 to 2055 under the climate change scenario where greenhouse gas concentrations are doubled by the year 2100



Source: Cheung *et al.* 2009a

In freshwater bodies and reservoirs, impacts might include:

- reduction in productivity as a result of accelerated eutrophication and intensified stratification;
- changing species composition (very likely loss of higher valued species) because of higher temperature and eutrophication;
- impacts of extreme high temperature on survival and normal development of aquatic animals at their early development stages; and
- increased susceptibility to disease as a result of changes in the pattern of aquatic epidemics (both aquaculture and natural populations).

Direct impacts on aquaculture production

De Silva and Soto (2009) note that climate change will have both direct and indirect impacts on aquaculture operations. Direct impacts refer to immediate physical, physiological and ecological impacts, whereas indirect impacts relate to associated issues such as feed availability and trade. Direct impacts as a result of changed environmental conditions at the site level *include changes in: water temperatures; monsoonal patterns; current and wave action; extreme climatic events; water stress; levels of eutrophication;*

and stratification in static waters (De Silva and Soto 2009, Handyside *et al.* 2006). Species used in aquaculture will have similar limitations to those favoured by capture fisheries, with temperature and/or salinity related impacts on physiological functions potentially *leading to changes in the optimal locations* and/or culturing/containment techniques for aquaculture operations for different species.

As mentioned earlier, there is high level of confidence that fish species are likely to suffer physiological constraints because of limited oxygen transport to tissues at high temperatures, and this is likely to have a considerable negative impact on aquaculture operations (Barange and Perry 2009). Warmer temperatures may also result in the increased frequency of disease, non-native species invasions and harmful algal blooms (Barange and Perry 2009, De Silva and Soto 2009, Handyside *et al.* 2006, Easterling *et al.* 2007).

The vast bulk of the world's aquaculture operations are located in tropical and subtropical areas of Asia, with finfish forming the most significant taxonomic group in freshwater, and crustaceans forming the bulk of brackishwater cultivation (De Silva and Soto 2009, FAO 2008b). The impact of climate change on these systems is difficult to predict, with different localities potentially facing challenges and opportunities in response to some of the impacts outlined above. Some of the most vulnerable systems may be inland temperate operations based on carnivorous finfish species. It is likely that inland species with lower saline tolerance may particularly need to be moved inland or replaced with more appropriate species.

Aquaculture may emerge as a more viable livelihood option to farming in certain areas, as changing salinity gradients impact farmland. Positive impacts may include increased production in non-carnivorous inland finfish because of greater availability of phytoplankton and zooplankton through eutrophication. This will mean that site-level investments in existing operations may be under threat, but also indicates that new opportunities may emerge elsewhere. (De Silva and Soto 2009, FAO 2008b).

Cage culture marine aquaculture will need to contend with extreme events, requiring new technology. Sea-level rise in low-lying coastal areas where a large proportion of aquaculture is conducted (e.g. deltaic areas) may result in operations having to move inland, thus competing for space with existing land-based activities. Aquaculture operations are likely to become more vulnerable to extreme climatic events. In tropical and subtropical Asia many aquaculture operations are small-scale and clustered together in geographical areas that are viable for aquaculture, but extreme events, including flooding, are likely to impact the livelihoods of many households (De Silva and Soto 2009, Cruz *et al.* 2007).

Given the predicted increase in drought periods in Asia, the water retention period enjoyed by non-perennial waterbodies may be reduced. This has implications for associated aquaculture operations, as it may reduce the opportunity to hold stocks for long enough to reach marketable sizes (De Silva and Soto 2009).

There may also be positive impacts on the aquaculture industry in certain areas. Warmer waters may lead to enhanced primary productivity and food conversion efficiencies, increasing the length of growing seasons and expanding the range of production for certain species (Easterling *et al.* 2007). However, the net benefits need to be considered as such positive impacts may not be enjoyed in isolation. Interactions with negative factors (e.g. feed availability and prices, water availability, vulnerability of operations to climate events) may mean that such positive impacts may not have uniformly positive outcomes in terms of benefits to livelihoods and economies.

Indirect consequences of projected changes

The *interactions between other sectors and the capture fisheries and aquaculture sectors need to be considered in policy planning*, with competing demands for limited resources, such as fertile land and freshwater, potentially challenging the viability of fisheries. The management of freshwater systems, for instance, has implications for both capture fisheries as well as aquaculture operations. *Competition for* *water between the fisheries and agriculture sectors already leads to conflicts between user groups*. Similar conflicts arise regarding the diversion of fresh water for water-thirsty industries, such as hydroelectric power generation.

Diversions can be implemented on a huge scale, completely altering water systems. For instance, water management policies driven by a range of needs in India and Bangladesh are responsible for an estimated 60 percent of the Ganges River's water flow being abstracted (Payne 2000). *Climate change is likely to lead to increased water stress for river basins in Asia*, further intensifying competition for water (Cruz *et al.* 2007). Water management policies tend to give little consideration to the importance of fisheries (IWMI 2005). Without proper cross-sectoral planning fisheries operations may lose out, with sectors enjoying greater political visibility and power enjoying greater responsiveness from policy-makers. *Promoting an ecosystem approach to fish production should enhance the integration of management with other sectors, providing a more holistic adaptation and mitigation approach to food production.*

The production of rice, maize and wheat has declined in many parts of Asia in the past few decades because of increasing water stress caused by a number of factors, including increasing temperature, increasing frequency of El Niño events and a reduction in the number of rainy days per year. IPCC projections note that a 2°C increase in air temperature will probably result in further reductions in the yields of these crops that could be in the range of 2 to 12 percent, depending on the crop, the locality and whether it is rainfed or irrigation fed (Cruz *et al.* 2007).

It is estimated that the world will need 70 to 100 percent more food by 2050, when the population is predicted to reach 9 billion people (World Bank 2008). It is speculated that the 2008 spike in food prices may mark the beginning of a pattern of rising and volatile food prices driven by growing demand from rapidly developing countries and competition from the biofuel industry (Charles *et al.* 2010). The need to utilize agricultural land efficiently may result in local-level competition for land in some areas, though the reduced viability of agricultural land in other areas may actually present opportunities for aquaculture. Certain feeds currently used by the aquaculture industry are based on crops such as soybean, corn and rice, causing the industry to intersect with competing demands from the agriculture and biofuel industries (De Silva and Soto 2009).

The need to utilize agricultural land efficiently may result in local-level competition for land in some areas, though the reduced viability of agricultural land in other areas may actually present opportunities for aquaculture.

Feed availability for the aquaculture industry will also be affected by changes in the capture fisheries sector. Various studies carried out by the Asia-Pacific Fishery Commission (APFIC) and the Australian Centre for Agriculture Research (ACIAR) have found that *low-value/trash fish species generally utilized for fishmeal production account for approximately 25 percent of the total marine capture landings in the region, with values ranging between 4 and 38 percent in seven countries in South, Southeast and East Asia* surveyed (APFIC 2006).

Potential climate change impacts on these stocks in the region will have huge implications on the availability of fish for feed and, subsequently, the viability of aquaculture operations dependent on fishmeal.

Potential climate change impacts on these stocks in the region will have huge implications for the availability of fish for feed and, subsequently, the viability of aquaculture operations dependent on fishmeal. Current analyses of fishmeal production have noted that production is unlikely to increase significantly whereas demand is likely to grow with the continued growth of the aquaculture industry (FAO 2008b). There is already considerable concern over the viability of low-value fish stocks in serving an expanded fishmeal market; this industry is likely to be oversubscribed even before taking into account the potential impacts of climate change. It is possible that the global market may see further decreases in raw material for fish feed*, and opportunities for non-fed aquaculture such as filter-feeders (e.g. bivalves) and seaweeds.*

The impacts of the fishing sector itself on the resilience of fisheries systems to climate change should also be considered. Barange and Perry (2009) summarize how fishing makes fish populations more sensitive to negative impacts by: removing older age classes and spatial subunits; influencing life history traits (e.g. reducing the age-at-first spawning); reducing fish mean size; and increasing the turnover rates of the fish component of marine communities. Such factors make populations more susceptible to the stresses caused by climate variability and change.

It should be recognized that adaptive strategies developed for other sectors (e.g. water, agriculture, coastal management) may have implications for the fisheries and aquaculture sectors. For instance, adaptive actions aimed at improving coastal defence through engineering solutions may impact fisheries habitats negatively. There may also be positive opportunities in extrasectoral responses. For instance, the protection of ecosystems for coastal protection or emissions reductions may actually enhance fisheries (e.g. forests associated with inland fisheries or mangrove ecosystems, Badjeck *et al.* 2009).

Potential direct impacts of climate change on the Asian region

One of the clear messages emerging from the authoritative and internationally recognized climate change review process developed under the Inter-governmental Panel on Climate Change (IPCC) is that climate change will not have uniform impacts across the globe. Given the complexity of the earth's climatic system, different physical and biotic systems, regions, and even localities, will be affected differently. The interconnected nature of the earth's climatic system means that ultimate outcomes will be the result of a multitude of interactions between a range of physical and biotic components as well as the potential effects of random (stochastic) events (e.g. large volcanic eruptions).

The magnitude of climate change will be contingent on how successfully greenhouse gas emissions will be reduced over the next few decades and whether carbon sequestering mechanisms are successfully maintained and enhanced (e.g. through preventing deforestation, supporting appropriate afforestation). Therefore projections of the future are premised on different scenarios that are themselves often based on a range of expected atmospheric greenhouse gas concentration levels. These projections can therefore only provide guidelines for the types of changes that are likely to occur. Although it is difficult to accurately determine what the exact response of the earth's climate will be in 50 to 100 years, it is possible to get an idea of what kind of trends to expect.

Different countries in Asia will face different kinds and levels of risks

Risk analyses based on variables such as potential climate change impacts on the sector, relative economic and social dependency on the sector, and adaptive capacity, have identified parts of Asia where climate change may have a variety of different implications.

Socio-economic impacts may have different emphases depending on the role of the sector at the national and local levels, for instance: nutritional dependence on fisheries resources is high in much of Southeast Asia as well as other countries such as Bangladesh, Japan and Sri Lanka. Countries with the largest fisheries landings in the region are China, Japan, Indonesia, India and Bangladesh. Dependency on the fisheries sector for export income is highest in the coastal nations of Southeast Asia.

Allison *et al.* 2009

The impacts of climate change are likely to be far from uniform and it is expected that developing countries, including those in Asia, are likely bear the brunt of direct climate change impacts. The existing levels of geographical exposure of many countries in the region are likely to be exacerbated by climate change; this refers to the prevailing geographical conditions that are thought to contribute to current low levels of development, such as: climatic extremes that accompany El Niño and La Niña cycles and monsoon cycles; variability in rainfall (both inter- and intra-annually); and high temperatures. Tropical geography may also have negative impacts on agricultural outputs as a result of pests, higher crop respiration rates and difficulties in water availability (Stern 2007).

Certain trends and impacts may be more pronounced in Asia (e.g. temperature increases are likely to be above the global norm in many parts of the region; a number of important river basins in Asia are threatened by further water stress; people in the region are likely to be disproportionately impacted by flooding; biodiversity loss will be greater in the tropics). Moreover, it is recognized that Asia is highly vulnerable to climate change because of the low capacity of countries in the region to respond and adapt; many countries cannot cope with current levels of climatic variability and extreme events, indicating that existing systems would be overwhelmed (Preston *et al.* 2006). As a region that is still beset with poverty and low levels of development, it is likely that only sudden, disaster-related climate change related issues will be addressed (Michel and Pandya 2010). There is a possibility that slower processes, such as rising sea levels and gradual shifts in agricultural and fisheries related production systems may be ignored, even if planning ahead for these changes will ultimately increase the chances of coping with negative impacts.

Some of the most significant impacts that climate change is likely to have on the Asian region, as projected for the twenty-first century and synthesized by the IPCC (Cruz *et al.* 2007)[5] are summarized in the following sections.

Surface air and water temperatures

Past and present climatic observations reveal trends of increasing surface air temperatures in Asia, with increases in some parts of the region during recent decades ranging between less than 1ºC to as much as 3ºC per century. Projected rates of warming for the twenty-first century will differ from the global mean in certain areas, and are:

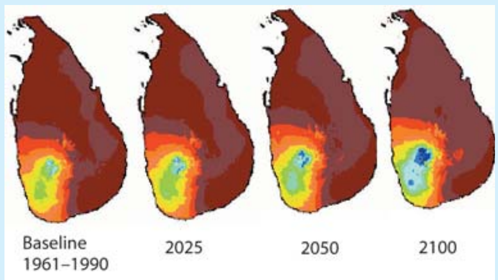
- significantly higher than the global mean in Central Asia, the Tibetan Plateau and Northern Asia;
- somewhat above the global mean in East Asia and South Asia;
- similar to the global mean in Southeast Asia; and
- higher during the northern hemispheric winter than during summer for all time periods over all subregions of Asia.

Additionally, *inland water systems will experience greater rates of heating than ocean systems.* Inland water temperatures are closely related to the hydrological system (Cochrane *et al.* 2009, Ficke *et al.* 2005) therefore predicted changes to precipitation patterns will have corresponding impacts.

In terms of the open ocean, temperature changes down the water column are determined by complex patterns of radiation, convection and mechanical turning. These processes are thought to be more rapid in tropical latitudes (UNEP 2009), indicating that *countries in Asia may be affected by these phenomena sooner than countries in other regions.*

Weather patterns and extreme climatic events

Predicted rainfall shift in Sri Lanka
red = low rainfall, blue high = rainfall



Interseasonal, interannual and spatial variability in rainfall trends have been observed across Asia over the past few decades. Some areas are experiencing decreasing trends in mean annual rainfall (e.g. Northeast and North China, the coastal belts and arid plains of Pakistan, parts of Northeast India, Indonesia, Philippines and some areas in Japan) with others conversely experiencing an increasing trend (e.g. Western China, Changjiang Valley and the southeastern coast of China, Bangladesh and along the western coasts of the Philippines). There is a trend toward an increased intensity of rainfall, but an overall decrease in the amount of rainfall. This has led to an increase in frequency of occurrence of more intense rainfall events in many parts of Asia, resulting in severe floods, landslides and mudflows. At the same time, a decreasing tendency in the number of rainy days and the total annual amount of precipitation has been reported.

There is a trend towards increased intensity and/or frequency of extreme weather events (depending on the location) throughout the twentieth century. The frequency and intensity of tropical cyclones originating in the Pacific have increased over the last few decades. However, cyclones originating from the Bay of Bengal and the Arabian Sea have been noted to decrease in frequency since 1970, but the intensity of these cyclones has increased. There is an overall increase in the damage caused by intense cyclones in affected countries, particularly Cambodia, China, India, Japan, the Philippines and Viet Nam.

[5] Findings presented are from Cruz *et al.* (2007) unless otherwise stated.

A rise in temperature during the summer and normally drier months, and during ENSO[6] (El Niño) events are thought to be responsible for the increasing frequency and intensity of droughts in many parts of Asia. Significantly longer heatwave duration has been observed in many countries. The majority of glaciers in Asia appear to be melting faster in recent years than before, with increases in glacial runoff and frequency of glacial lake outbursts causing mudflows and avalanches in certain areas.

Projections note that:

- It is likely that annual *precipitation* will increase across most of Asia during the twenty-first century with seasonal and subregional variations.
- There is likely to be an increase in occurrence of *extreme weather events* including heatwaves and intense precipitation events in South Asia, East Asia, and Southeast Asia.
- There may be a 10 to 20 percent increase in tropical *cyclone intensities* in East Asia, Southeast Asia and South Asia.
- There is the possibility of the amplification of *storm-surge heights* that will result in an increased risk of coastal disasters along the coastal regions of East, South and Southeast Asian countries.

Freshwater systems

Inland water systems are governed largely by hydrological cycles and projected changes in these will lead to altered intensities and timings of freshwater flows. It is possible that by the middle of the twenty-first century average river runoff will decline by between 10 and 30 percent in the mid-latitudes and dry tropics; the wet tropics may conversely see increases of between 10 to 40 percent (Milly *et al.* 2005). In addition to this, current patterns of temporal variability may be magnified, with increases in maximum flows and decreases in minimum flows in some parts of Asia, such as the Mekong. This may result in increased flooding risks in the wet season and increased water shortages in the dry season (Cruz *et al.* 2007).

Demand for freshwater is likely to grow over the course of the twenty-first century whereas, conversely, availability is set to decrease. Freshwater availability, particularly in large river basins, in Central, South, East and Southeast Asia is projected to decrease because of climate change which, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by the 2050s.

In many countries in South Asia (i.e. Bangladesh, India, Nepal and Pakistan) climate change is an additional factor that is aggravating water shortages that are largely caused by poorly planned resource management spurred by rapid urbanization and industrialization, and compounded by population growth. Water basins found in South Asia and Northern China are already experiencing water stress (i.e. have a per capita water availability of less than 1 000 m^3yr^{-1}). Ecosystems and human populations in these regions will be particularly sensitive to climate change related decreases or variability in precipitation (Kundzewicz *et al.* 2007).

Oceans, coastal zones and sea-level rise

Many coastal areas in Asia are highly sensitive to climate change because of: the nature of the underlying physical geography and geology of many coastal areas; high population density and infrastructure development in these areas; and the low capacity for populations in these areas to adapt.

[6] El Niño/La Niña-Southern Oscillation, or ENSO, is a climate "pattern" that occurs across the tropical Pacific Ocean at, on average, five-year intervals. It is characterized by variations in the temperature of the surface of the tropical eastern Pacific Ocean—warming or cooling (known as El Niño and La Niña) which are linked to air surface pressure in the tropical western Pacific—the Southern Oscillation. ENSO causes extreme weather (such as floods and droughts) in many regions of the world. Developing countries dependent on agriculture and fishing, particularly those bordering the Pacific Ocean, are the most affected. In popular usage, the El Niño-Southern Oscillation is often called just "El Niño".

The current, average rate of sea-level rise in coastal areas of Asia is reported to be between 1 to 3 mm/yr, which is slightly higher than the global average. As a result coastlines will be subjected to:

- Increased erosion
- Inundation
- Flooding
- Loss of coastal wetlands
- Saline intrusion into rivers, bays and aquifers (see table 3 for an example).

Table 3 Areas affected by saline water intrusion in Mekong Delta area under different scenarios (ha) (Nguyen Lam Anh, unpublished)[7]

Salinity (ppt)	2005	Sea level rise scenarios		
	0 cm	+ 30 cm	+ 50 cm	+ 75 cm
<4	478 241	643 712	745 082	809 178
4–10	236 089	251 483	274 491	324 221
10–20	227 650	261 394	253 051	257 350
>20	938 029	924 335	916 691	912 664
Total	**1 880 009**	**2 080 924**	**2 189 315**	**2 303 413**

In certain coastal areas of Asia, a 30 cm rise in sea level could result in 45 m of landward erosion. Even under conservative estimates it is expected that sea level rise will result in an increase in the annual number of people globally affected by flooding from 13 million to 94 million by the end of the twenty-first century. Asia will be disproportionately affected by this, with 60 percent of this increase occurring in South Asia and 20 percent in Southeast Asia. Deltaic areas that are dependent largely on monsoonal patterns and river-based sediment deposition for land-building may be particularly sensitive to land loss that will be compounded by sea-level rise. The large, populated mega-deltas in Asia are thought to be acutely vulnerable to climate change (Nicholls *et al.* 2007, Cruz *et al.* 2007), indicating that *huge societal and economic impacts may be sustained if delta systems are adversely affected.*

Coral reef ecosystems are already weakened as a result of the El Niño event in 1997/1998 – up to 34 percent of reefs were thought to have been lost because of this one event (Wilkinson, 2000). Climate change related impacts are *likely to result in the further degradation of coral reef ecosystems* and adversely impact species directly (Munday *et al.* 2008).

The open ocean may undergo changes in circulation systems as a result of temperature changes. Additionally, for the last two centuries the ocean has played a role in absorbing atmospheric carbon, resulting in the acidification of the top 2 000 m of the ocean's waters. Ongoing acidification of oceanic waters will have negative implications for calcifying organisms, including corals (UNEP 2009).

Health-related risks

Coastal areas, in South, East and Southeast Asia, particularly heavily-populated mega-delta regions, will be at greatest risk of increased sea-based flooding and, in the case of some mega-deltas, river-based flooding. The prevalence of diarrhoeal disease associated with floods and droughts are expected to rise in East, South and Southeast Asia. Temperature increases will support the proliferation of a range of bacterial diseases including diarrhoeal diseases and cholera. Deaths as a result of heatwave events are also likely to increase, with parts of India and Russia already experiencing high levels of heatwave-related deaths, with vulnerable groups such as the poor, elderly and manual labourers being particularly at risk. Climate change related heat stress combined with air pollution may also exacerbate respiratory and cardiovascular disease rates. Vector borne diseases such as malaria and encephalitis are likely to increase both in incidence and geographical range with increasing temperatures. These patterns may have complex interactions with other factors (e.g. the development of pesticide resistant strains of malaria-transmitting mosquitoes).

> ***"The most vulnerable areas of Southeast Asia as being: all the regions of the Philippines, the Mekong River Delta region of Viet Nam; almost all the regions of Cambodia; Northern and eastern Lao People's Democratic Republic; the Bangkok region of Thailand; and the west and south of Sumatra, and western and eastern Java in Indonesia."***
>
> **Yusuf and Francisco 2009**

[7] Presented at the APFIC/FAO Regional Consultative Workshop "Implications of climate change on fisheries and aquaculture: challenges for adaptation and mitigation in the Asia-Pacific Region", 24–26 May 2011, Kathmandu, Nepal.

Diseases known to exhibit a strong correlation with temperature increases such as *Oncomelania*, schistosomiasis, cerebral infarction and cerebral ischemia, may also experience increases in range and incidence.

Agriculture and food production

It is projected that global cereal prices will increase by more than 300 percent by 2080 as a result of productivity declines. How climate change is likely to affect food supply and demand in Asia is very uncertain. Greater variability in hydrological characteristics, coupled with increases in temperature, is likely to affect grain supplies and food security in the region. Climate change induced temperature increases, drought, flooding and soil degradation are likely to result in an overall decrease in agricultural productivity, although increases in the yields of certain crops in certain parts of Asia may occur; rice, maize and wheat yields may exhibit regional differences in terms of response. Subsistence producers are likely to be at greatest risk of productivity declines and loss of genetic diversity of crops. An additional 49 million people could be at risk of hunger by 2020, with up to 266 million additional people at risk by 2080.

Overall regional production of these three crops has declined in the past few decades in many parts of Asia because of increasing water stress. Surface air temperature increases may also play a part in this. Most of the arable land in Asia is currently in use and it is likely that climate change will have an impact on the area of crop production with a general northward shift in agricultural zones. Irrigation needs are likely to increase by a factor of 10 percent in response to a 1°C rise in temperature in order to sustain productivity in South and East Asia. Rainfed crops in certain parts of the region may also face challenges. Livestock production and milk yields could suffer a general decrease, with temperate grassland-based production likely to shift northwards. Increases in pests and disease will contribute to these trends in crop yields and livestock production.

Impact of projected changes on livelihoods and economies in Asia

The previous sections have focused largely on the direct, practical impacts of climate change on ecosystems and services as well as on the possible consequences for fisheries and aquaculture systems. Understanding how this translates into impacts on lives, livelihoods and economies will allow us to identify groups most at risk and develop appropriate interventions.

Vulnerability of fisheries and aquaculture-dependent communities

The vulnerability of fisheries and aquaculture dependent communities and economies to climate change will be based on several factors, as defined by the IPCC (2001b):

- the exposure of the system to climate change ("the nature and degree to which a system is exposed to significant climatic variations");
- the sensitivity of the system to climate change ("the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli"); and
- the adaptive capacity of ecosystems and human societies that are going to experience these impacts ("the ability of a system to adjust to climate change (including climate variability and extremes), to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences.").

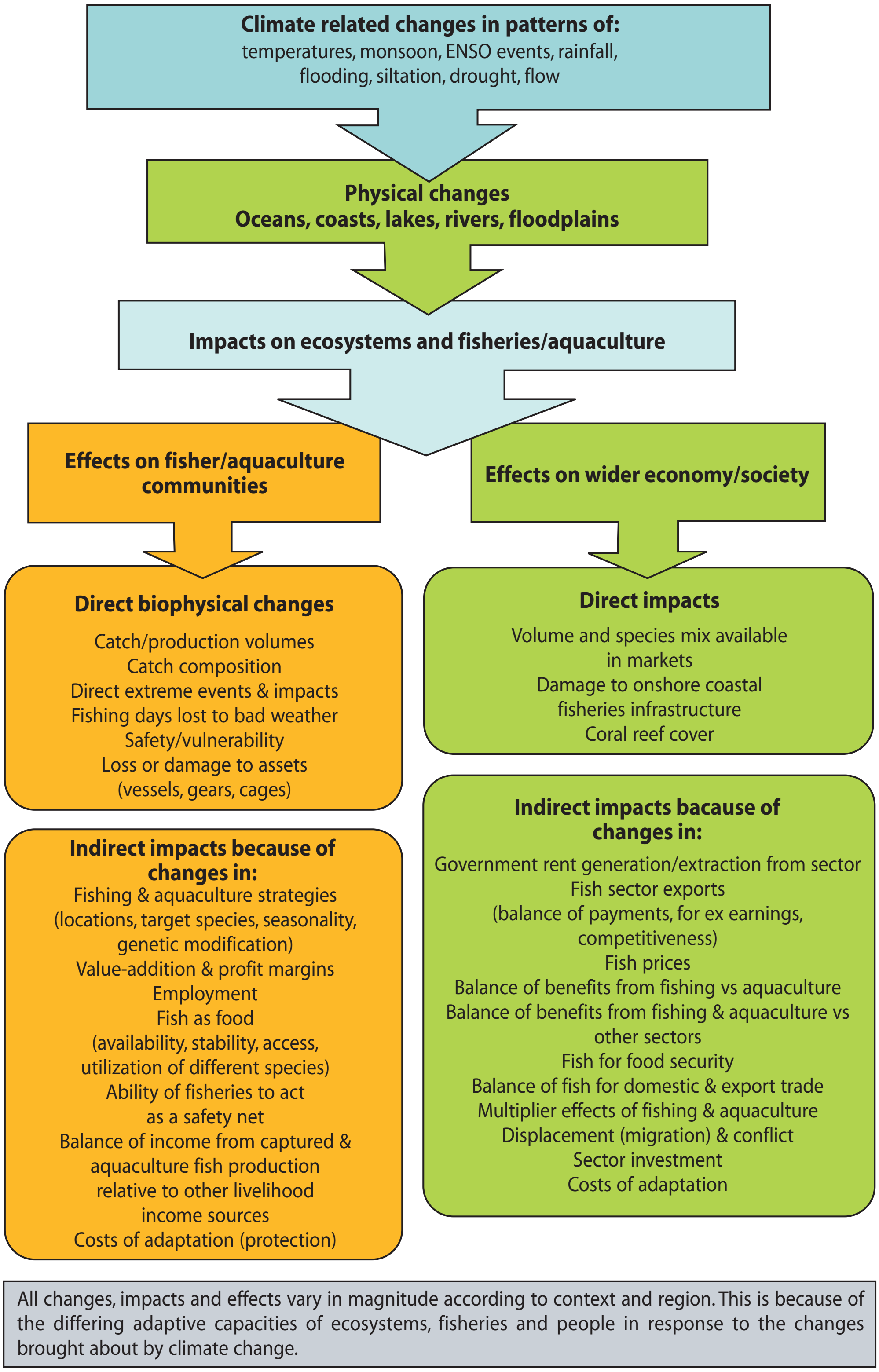
The fisheries and aquaculture sectors employ a significant amount of people in the Asian region as well as form the basis of the cultural identity of communities. The most significant economic consequences of climate shocks on Asian fisheries will have the biggest impact on the poorest consumers, threatening broader food security as well as fisheries-based livelihoods (see figure 2 for a general view of the impacts of climate change). There is a growing consensus that climate change impacts on capture fisheries and aquaculture are going to have a disproportionately negative impact on the economies and livelihoods of nations and communities in Asia. For instance, recent analyses by Allison *et al.* (2009) indicate that African and Southeast Asian countries will be the most economically vulnerable to negative impacts on these sectors.

The impacts of climate change are likely to be far from uniform and it is expected that the Asian region will face very specific and locally variable challenges. Certain trends and impacts may be more pronounced in Asia (e.g. temperature increases are likely to be above the global norm in many parts of the region; a number of important river basins in Asia are threatened by further water stress; people in the region are likely to be disproportionately impacted by flooding; biodiversity loss will be greater in the tropics).

> ***Countries that are highly dependent on the fisheries sector and have a low capacity to adapt will be most at risk of serious socio-economic impacts***
>
> The river dependent countries of Bangladesh, Cambodia and Pakistan have been identified as three of the most at risk countries in the region in this respect.

Moreover, it is recognized that Asia is highly vulnerable to climate change because of the low capacity of countries in the region to respond and adapt. Many countries cannot cope with current levels of climatic variability and extreme events, indicating that existing systems would be overwhelmed (Preston *et al.* 2006). As a region that is still beset with poverty and low levels of development, it is likely that only sudden, disaster-related climate change related issues will be addressed (Pellawatta 2010). There is a possibility that slower processes, such as rising sea levels and gradual shifts in agricultural and fisheries-related production systems could be ignored, even if planning ahead for these changes will ultimately increase the chances of coping with negative impacts.

Figure 2 Climate change implications for fishers, communities and national economies



Source: Adapted from McFadyen and Allison (2009)

Analyses of location specific climate change vulnerability tend to look at a number of different variables in order to calculate the expected risks posed to localities in terms of threat to lives, livelihoods, infrastructure and economic health. Such variables generally may examine: exposure to climatic variables; the sensitivity of local systems to climate change related stimuli; and the capacity of local populations to adapt to climate change, e.g. resources and human capacity (Allison *et al.* 2009, Patt *et al.* 2009, Yusuf and Francisco 2009).

A nation's capacity to adapt to climate change will greatly influence the magnitude of socio-economic disturbance experienced, to the point where for certain countries, such as Cambodia, despite overall exposure risks being moderate, a lack of adaptive capacity means that overall vulnerability is still high. For other countries, such as Indonesia, where adaptive capacity is relatively high, factors including high population density contribute to making certain localities highly vulnerable (Yusuf and Francisco 2009).

A nation's capacity to adapt to climate change will influence the magnitude of socio-economic disturbance experienced

Bangladesh, Lao People's Democratic Republic, Nepal, and Pakistan, are believed to have the lowest capacity in the region to adapt to climate change related impacts to the fisheries sector.

Understanding geographical patterns of vulnerability in the region

Though this is a new and emerging field of practice, research carried out to date provides a useful indication of which geographical localities may merit greater attention and investment in terms of vulnerability reduction (see Table 4 for a summary of findings from various research papers). Recent analyses by the Economy and Environment Program for Southeast Asia (EEPSEA), for example, have identified the *most vulnerable areas of Southeast Asia as being: all the regions of the Philippines, the Mekong River Delta region of Viet Nam; almost all the regions of Cambodia; Northern and Eastern Lao PDR; the Bangkok region of Thailand; and the west and south of Sumatra, and Western and Eastern Java in Indonesia* (Yusuf and Francisco 2009). This study notes that the vulnerable are marked by their exposure to sea-level rise or, in the case of northern Philippines, their exposure to extreme weather events. Cambodia's vulnerability is exacerbated largely by its low adaptive capacity.

Other studies note that Bangladesh, Lao People's Democratic Republic, Nepal, and Pakistan are believed to have the lowest capacity in the region to adapt to climate change related impacts on the capture fisheries sector (Allison *et al.* 2009). According to all vulnerability assessments, South Asia is the region most vulnerable to the impacts of climate change. Many of this region's countries, including Bangladesh, India, Maldives, and Pakistan, are expected to be among the most affected in the world. Environmental harm as a result of sea-level rise in association with storm surge impacts will be significant in both the Bay of Bengal and the Arabian Sea, where cyclonic activity is projected to intensify. The delta areas of the Ganges-Brahmaputra, Godavari, Indus, Krishna, and Mahanadi rivers also experience cyclonic activity, and these rivers are likely to flood more often with increased monsoonal activity (ADB 2011).

The link between patterns of socio-economic dependence and vulnerability

Socio-economic impacts may have different emphases depending on the role of the sector at the national and local levels, e.g. nutritional dependence on fisheries resources is high in much of Southeast Asia as well as other countries, such as Bangladesh, Japan and Sri Lanka whereas dependence on the fisheries sector for export income is highest in the coastal nations of Southeast Asia. Countries with the largest fisheries landings in the region are Bangladesh, China, India, Indonesia and Japan (Allison *et al.* 2009).

Certain small developing states may depend heavily on the capture fisheries sector for rent generation through fees associated with fishing, processing and trading (e.g. licence fees from fishing fleets; vessel registration fees; landing, export and import taxes). These revenues may be used for general budget support and expenditures outside the fisheries sector (McFadyen and Allison 2009).

Table 4 Probable climate effects and consequent sectoral vulnerabilities in Asia

Climate changes	
Temperature	– Warming above the global mean in Central Asia, the Tibetan Plateau, North, East and South Asia – the warming will be similar to the global mean in Southeast Asia. – Fewer very cold days in East Asia and South Asia. – Species shifts and local extinctions in tropical areas as a result of temperature rise.
Precipitation, snow and ice	– Increase in precipitation in most of Asia. Decrease in precipitation in Central Asia in summer. – Increase in the frequency of intense precipitation events in parts of South Asia and in East Asia. – Increasing reduction in snow and ice in Himalayan and Tibetan Plateau glaciers.
Extreme Events	Increasing frequency and intensity of extreme events particularly: – droughts during the summer months and El Niño events; – increase in extreme rainfall and winds associated with tropical cyclones in East Asia, Southeast Asia and South Asia (especially Bay of Bengal, Arabian Sea, Mekong Delta, Lao People's Democratic Republic, Viet Nam, Philippines); – intense rainfall events (monsoon related) causing landslides and severe flooding; – increase in storm surges and associated coastal flooding; and – heatwaves/hot spells in summer of longer duration, more intense and more frequent, particularly in East Asia.
Sectoral vulnerabilities	
Water	– Increasing water stress to over a hundred million people because of a decrease of freshwater availability in Central, South, East and Southeast Asia, particularly in large river basins such as Changjiang. – Increase in the number and severity of glacial melt-related floods, slope destabilization followed by decreases in river flows as glaciers disappear. – Severe river flooding related to intensified monsoon rainfall.
Agriculture and food security	– Decreases in crop yield for many parts of Asia putting many millions of people at risk from hunger. – Reduced soil moisture and evapotranspiration may increase land degradation and desertification. – Increased soil loss and erosion may reduce agricultural productivity in some areas. – Agriculture may expand in productivity in northern areas.
Health	– Heat stress and changing patterns in the occurrence of disease vectors affecting health. – Increases in endemic morbidity and mortality because of diarrhoeal disease in South and Southeast Asia. – Increase in the abundance and/or virulence of cholera in South Asia. – We may assume similar patterns for aquatic animal health.
Terrestrial ecosystems	– Increased risk of extinction for many species as a result of the synergistic effects of climate change and habitat fragmentation. – Northward shift in the extent of boreal forest in North Asia, although likely increase in frequency and extent of forest fires could limit forest expansion.
Coastal zones	– Tens of millions of people in low-lying coastal areas of South and Southeast Asia affected by sea-level rise and an increase in the intensity of tropical cyclones and storm surges. – Coastal inundation is likely to affect seriously the aquaculture industry and infrastructure particularly in heavily-populated mega deltas. – Stability of wetlands, mangroves, and coral reefs increasingly threatened. – Salinization of deltas affects water quality and ecosystem services.

Vulnerability of river basins

Key river basins in Asia, such as the Mekong, the Ganges-Meghna-Brahmaputra, and the Irrawaddy harbour centres of intense inland fishing and aquaculture activity that are very significant to local livelihoods as well as contributing to national export incomes that are hugely economically significant (De Silva and Soto 2009).

Vulnerable countries in Asia that depend on river and deltaic fisheries based on the Himalayan mountain system, such as the Indus, Brahmaputra, Ganga and Mekong, may be subjected to earlier season peak flows and potential reduction in flows as a result of reduced snowfall and melting (Barnett *et al.* 2005, Cruz *et al.* 2007).

Regional patterns of vulnerability

Vulnerability studies carried out specifically for the fisheries sector use similar approaches, specifically focusing on the type and magnitude of economic and livelihood dependence on the fisheries sector as well as appraising the potential impacts of climate change on key fisheries resources. *Countries that are highly dependent on the fisheries sector and have a low capacity to adapt will be most at risk of serious socio-economic implications* as a result of negative impacts on the fisheries sector. Of 132 countries analysed for the vulnerability of the capture fisheries sector to climate change in a study by Allison *et al.* (2009), *four tropical Asian countries (Bangladesh, Cambodia, Pakistan and Yemen) were identified as most vulnerable;* all but one of these countries (Yemen) are highlighted for their dependency on river-based fisheries. This analysis looked at: predicted impact of climate change; the relative importance of fisheries to national economies and diets; and limited national and local capacity to adapt to impacts and opportunities.

Cheung *et al.* (2009b) in a slightly different analysis of changing global marine capture fisheries catch potential in the 50-year period between 2005 and 2055, found that the countries in Asia that were likely to be most affected on a macro-economic level by declining catch potential (i.e. countries with significant EEZs and nationally significant fisheries) were China and Indonesia. Tropical countries were again seen to take the greatest hit in terms of catch potential and tropical Asian nations were expected to suffer socio-economic and food security related losses as a result of reducing catch potential.

Understanding gender-related patterns of vulnerability in the region

The effects of climate change are likely to affect men and women differently because of gender differences in cultural, social and economic roles, property rights and access to information. Many studies have determined, that in inequitable societies, poor women are more vulnerable to natural disasters given socially-determined gender roles and behaviour (Patt *et al.*2009). The figures are devastating, with women and children being 14 times more likely to die than men during a disaster (IUCN 2007). In the 1991 cyclone disaster that killed 40 000 in Bangladesh, 90 percent of the victims were women (Aguilar, 2004, cited in IUCN 2007). Although not related to climate change, the 2004 tsunami provided a clear picture of the different vulnerabilities between genders as more women died than men – in Indonesia and Sri Lanka, for example, male survivors outnumber female survivors by 3 or 4 to 1 (Davis *et al.* 2005, cited in IUCN 2007). Boys are taught to swim and climb trees, whereas social prejudice keeps women from learning these survival skills, thus limiting their chances of survival in a flooding disaster.

There are particular gender dimensions, including competition for resource access, risk from extreme events and occupational change in areas such as markets, distribution and processing, in which women currently play a significant role (FAO 2008b). In the event of a tsunami, men that are out fishing may have more chance of survival than the women and children that are inshore (Oxfam 2011). There is also a greater number of women than men working in the informal sector, which has been the worst hit and least able to recover from the effects of past disasters. (Nelson *et al.* 2002). After a disaster, household workload increases substantially, forcing girls to drop out of school to help with the household chores. In the fish processing sector a large portion of the labour is done by female workers, thus any threat to fishery or aquaculture production may have a disproportionate gender impact.

Overall implications for sustainable development in Asia

A number of countries in the region are characterized by high population densities and growth rates, along with rapid rates of industrialization and urbanization, placing intense pressure on natural resources, including key landscapes such as flood plains, forests and river basins. The *erosion of the ecosystem services* these systems provide by development trends and climate change will *place populations in a position of greater vulnerability*. Patterns of migration and conflict are likely to be influenced by these patterns. *Food security and rates of malnutrition are likely to be negatively impacted* because of the sensitivity of agricultural systems. Without appropriate measures, the economic growth of Asia is likely to slow down as a result of climate change and the consequences of unsustainable development patterns. Financial costs associated with damage to infrastructure and property as a result of extreme events are projected to rise. The poor are likely to be disproportionately impacted by projected trends, and poverty rates may increase.

> ***The poor are likely to be most affected***
>
> Disruption to the fisheries sector may have a disproportionate impact on the large number of poor people in Asia who depend on the sector for their protein intake and employment, and who are likely to be more vulnerable to hazards and extreme events.

Socio-economic implications of climate change for Asia

Despite the uncertainty over the local impacts of climate change, it is widely understood that developing countries, particularly *poor communities living in marginal conditions, will experience a disproportionately negative impact*. The Stern review concluded that developing countries are inherently more vulnerable to climate change. The factors responsible (Stern 2007) can be summarized as follows:

Developing countries have higher levels of sensitivity to climate change

Livelihoods and economies in developing countries have a greater reliance on climate sensitive sectors such as agriculture and fisheries, as well as having a greater dependence on ecosystems. Economic activities are concentrated in the rural sector, limiting the ability of shifts to the non-rural sector.

Developing countries are experiencing high levels of population growth

An increasing global population will be accompanied by a growth in demand for food and water. For instance, it is estimated that the world will need 70 to 100 percent more food by 2050 (Godfray *et al.* 2010). The bulk of population growth over the next few decades is going to occur in developing countries, putting a strain on natural resources, including agriculture and water resources.

Developing countries already experience high levels of migration, climate change will make this worse

A recent Asian Development Bank review[8] has concluded that climate induced migration has been growing in recent years as a result of severe storms and flooding events. Millions of people have been driven to move for both the short-term and the long-term in countries such as China, Pakistan, the Philippines, and Sri Lanka. Because of its already high population densities, rural and coastal vulnerability, the Asian region is expected to experience more significant migration flows because of long-term changes in weather patterns and degrading environmental conditions than other parts of the world. It is impossible to estimate the likely number of affected people because these migrations cannot be dissociated from other drivers of human migration in the region, particularly economic migration. This is particularly the case for slow onset environmental changes. This is perhaps best illustrated by migration out of small island developing states. Climate effects are therefore an additional complicating factor in the already complex issue of human migration, but despite this, it remains possible to predict with some certainty that the scale and impact of climate on migration is likely to increase rather than decrease.

[8] Summarized from ADB 2011.

In the fishery and aquaculture sectors, vulnerabilities to coastal storms and flooding are already a reality with large displacements of people occurring regularly, and it is likely that the severity of impacts will increase. This reinforces the need for more attention to be paid to adaptation approaches and vulnerability reduction.

A lack of adequate water infrastructure and management

As developing countries are highly dependent on water for economic growth and development and are struggling to manage current levels of water demand; climate change is likely to negatively impact water availability and this, combined with population growth, is likely to disadvantage developing countries further.

Low incomes and underdeveloped financial markets

The capacity of the poor to recover from extreme events, through tapping into credit, loans and insurance, is very low. At the national level, there is a lack of sufficient financial reserves available to cushion economies from climate change shocks in poorer developing countries.

Lack of effective public services

A lack of resources to support public services, combined with poor governance, including corruption, generally lead to less effective development of crucial public sector services that could reduce the impacts of climate change on people's livelihoods (e.g. disaster warning and management systems, control of disease outbreaks).

Current patterns of growth and development in the region mean that certain countries in Asia are likely to exit the more vulnerable bracket and become increasingly better equipped to deal with climate change, but in other areas climate change will emerge as a fact that could limit growth and development prospects in a number of countries, for instance (Stern 2007):

- Falling agricultural outputs combined with poor conditions in rural areas will result in increased poverty, coupled to migration or shifting livelihood survival strategies.
- A focus on adopting strategies that allow communities to respond to the risks and impacts of climate change may lock people into long-term poverty traps.
- The financial drain of climate change on national economies may result in the decreased availability of revenue for other purposes, slowing down social and economic development.

In a review of studies examining the economic cost of climate change on the Asia-Pacific region, Preston *et al.* (2006) noted that most studies indicated that there would be overall economic losses at national levels as well as at the regional levels. The report notes that, although there may be limited positive impacts of climate change on specific sectors, the cumulative negative impact of climate change on multiple sectors is likely to threaten regional sustainability and prosperity.

Climate change adaptation and mitigation in the fisheries and aquaculture sectors

Having looked at the main implications of climate change, this section examines how the fisheries and aquaculture sectors in Asia should respond to the threats and causes of climate change in order to safeguard economies, livelihoods and critical ecosystems. Responses to climate change need to consider two broad issues:

- making adaptations in the sectors in order to withstand negative impacts as well as to capitalize on any opportunities; and
- mitigating the potential contribution of these sectors to greenhouse gas emissions.

Adaptive capacity varies between countries depending on social structure, culture, economic capacity, geography and level of environmental degradation.

Capacity is increasing in some parts of Asia, for example the success of early warning systems for extreme weather events in Bangladesh, the Philippines and Viet Nam. However, capacity is still constrained because of poor resource bases, inequalities in income, weak institutions and limited technology.

The IPCC refers to *adaptation practices as actual adjustments, or changes in social, economic or ecological systems, which may ultimately enhance resilience or reduce vulnerability* to observed or expected climatic stimuli or their effects (IPCC 2001a).

Mitigation is defined by the IPCC as technological changes and substitutions that reduce resource inputs and emissions per unit of output; this essentially means implementing policies to reduce emissions and enhance carbon sinks (IPCC 2007). The following sections will review some of the considerations regarding potential approaches to adaptation and mitigation given the unique circumstances of the Asian region.

Capture fisheries and aquaculture and climate change adaptation

Adaptation to climate change will come in the form of strategies and activities that are adopted in reaction to or in anticipation of changes. Even prior to our awareness of climate change related impacts, the fisheries sector has always been compelled to respond to the unpredictability of weather and stocks (Badjeck *et al.* 2009, Daw *et al.* 2009) requiring an adaptive approach to fisheries management. It is clear that the actual impacts of climate change on livelihoods at the local level are very difficult to predict, being interdependent on a range of factors that, other than complex climatic and earth system interactions, include socio-economic, institutional and cross-sectoral impacts. Understanding the values of different systems and services can help in decision-making and investment for adaptation. The costs of coral change and environmental degradation in the Pacific and India Oceans is summarized in the "Economic Values of Coral Reefs, Mangroves, and Seagrasses: A Global Compilation" (Conservation International 2008).

Aquaculture operations will be impacted directly by increasing temperatures and ambient environmental conditions that will impact on fish physiology as well as weather events and sea-level rise. Indirect factors that need to be considered include the availability and/or affordability of feed and other inputs, such as energy and freshwater. In terms of direct impacts, these will be locally variable and potentially difficult to predict with certainty, requiring institutional flexibility and responsiveness to be able to cope with impacts as and when they happen.

Existing examples of adaptation relevant to fisheries and aquaculture

Many countries in the region have developed National Communications under the United Nations Framework Convention on Climate Change (UNFCCC), outlining key adaptive measures. Existing approaches to climate change adaptation currently being pursued in the region include: the improvement of existing coastal protection systems; conservation and planting of mangrove forests; relocation of aquaculture farms and other coastal infrastructure; improvements in the design of housing and infrastructure; monitoring sea-level rise and mapping hazard and vulnerability risks; and increasing the awareness and knowledge of stakeholders.

Some adaptive actions are embedded in existing integrated management techniques. For instance, Integrated Coastal Zone Management (ICZM) provides a strong framework for adaptation measures in coastal areas and is accordingly reflected in the National Communications of countries such as Bangladesh, Indonesia and Malaysia. Other countries may have existing ICZM strategies that may or may not incorporate climate change related considerations, for instance Sri Lanka has an operational Coastal Zone Management Plan (CZMP) that lacks a sea-level rise component (Pellawatta 2010).

There is a need for action irrespective of climate change

As direct causal relationships between climate change drivers (versus other drivers) and changes to the systems will be hard (and costly) to determine, robust management strategies and policy will be needed, independently of the driver of change.

Other integrated approaches include Ecosystem-Based Management (EBM) which provides a more holistic framework for understanding how management interventions should be developed (Pellawatta 2010). Community-Based Adaptation (CBA) is an approach that has been developed to respond to the specific threats faced at the community level. CBA operates on the principle that poor and vulnerable communities can be supported and empowered to increase their own resilience to climate change (Pellawatta 2010).

Adaptation through improved governance

It should be recognized that *current patterns of fisheries and aquaculture management,* even before taking into consideration climate change impacts, *reflect governance limitations, with inadequate management and enforcement regimes and poor cross-sectoral coordination.* It is estimated that 75 percent of stocks are either fully exploited, overexploited, depleted or recovering; placing most commercially targeted capture fisheries species precariously at the edge or over the edge of sustainable use (World Bank and FAO 2008). Relatively recent estimates show that the biomass of coastal fishery resources in South and Southeast Asia have dipped to as low as 5 percent of their pre-fisheries expansion levels and upper limits hover at only 30 percent, with larger, valuable species taking the brunt of this decline (Silvestre *et al.* 2003). Ever-increasing global demand for seafood is driving the rapid growth of the aquaculture sector. However, land availability, sustainable feed sourcing and the challenge of adhering to environmental and food standards overshadow the industry's growth. Often *policy agendas are set on the basis of precedent and tradition and are rarely a clinical response to empirically determined facts,* which is one of the reasons why it is difficult to get fisheries policies to move away from the narrow historical focus of setting production targets (IMM 2002).

Good governance is essential for effective adaptation

The need to reverse patterns of poor management and governance has never been greater. Fisheries governance processes that are meaningfully stakeholder inclusive, transparent, based on best practice (e.g. the implementation of international fisheries agreements and codes) and tackle issues of corruption and group marginalization, will provide the sector, and those whose livelihoods and food security depend on it, with a better chance of adapting to climate change. Tackling existing incentive structures that make bad practices lucrative may be an important component of this.

Supporting governance and natural resource management institutions to be flexible and responsive to unpredictable natural events as well as to incorporate cross-sectoral considerations will be critical in the face of climate change. For example, adaptation measures for the freshwater aquaculture subsector are only likely to be successful if carried out on a watershed level, hinging on cross-sectoral coordination (De Silva and Soto 2009). This necessitates an appreciation and active promotion of good governance as a crucial first step. Decentralization, comprehensive stakeholder consultation, the presentation of proper justifications for policy decisions, and institutional reform are often presented as a means for achieving this (Bene *et al.* 2007, World Bank and FAO 2008).

Transparency and good governance can positively enhance national adaptive capacity. Key elements may include:

- supporting science-based decision-making processes that are responsive and accountable to all stakeholders;
- strengthening key institutions such as fisheries administrations, fisher co-operatives, relevant civil society institutions;
- enabling local government agencies to make specific policy decisions based on differentiated local needs;
- identifying and resolving perverse incentives, which are counter-productive to good governance;
- tackling patterns of corruption and patronage that may lead to decision-making based on short-term vested interests;
- ensuring cross-sectoral collaboration is made possible (e.g. developing multisector decision-making bodies; ensuring fisheries and aquaculture considerations are reflected in key development policies such as national development strategies and poverty reduction strategy papers; removing interdepartmental competition for power and resources);
- incorporating integrated governance approaches, such as integrated coastal management (ICM) and the Ecosystem Approach to Fisheries (EAF) management in policy objectives can assist in making important extrasectoral links. EAF, for instance, can be linked to ecosystem-based adaptation such as the use of coastal ecosystems for shoreline protection that can also contribute to fisheries habitat management, biodiversity protection and the tourism sector (McFadyen and Allison 2009);
- adopting the ecosystem approach to aquaculture, which emphasizes the integration of other sectors, especially the potential of integrated aquaculture-agriculture and aquaculture-sylviculture (Troell 2009); and
- developing gender differentiated data on the impact of climate change and emphasizing the capacities of men and women to adapt and mitigate climate changes. A specific focus on the possible advantages of implementing gender-sensitive adaptation projects (IUCN 2007) should be considered.

Integration of fisheries and aquaculture in general climate change adaptation and response initiatives

Policy-makers should seek for the integration of fisheries and aquaculture considerations in other areas of climate change adaptation. In terms of adaptation strategies pursued by other sectors, this would require a holistic appraisal of adaptive measures for different sectors to understand the negative and positive implications. With regards to disaster risk management (DRM), preparedness and response policies, the damage suffered by the fisheries and aquaculture sectors will be reduced if fishers and aquaculture operators are explicitly included in disaster risk management plans (McFadyen and Allison 2009). Furthermore, integrated solutions to climate change can have multiple benefits if cross-sectoral considerations are taken into account. For instance, the use of replanted mangrove for coastal protection both improves physical protection from coastal storms as well as provides improved fisheries resources for local communities (WDR 2001).

Specific policy-level actions targeted at the fisheries and aquaculture sectors may include (McFadyen and Allison 2009):

- co-ordinating with agencies responsible for climate change adaptation and disaster preparedness and response policies to ensure that fisheries and aquaculture concerns are integrated in key policies and initiatives (e.g. National Plans of Adaptation (NAPAs));
- capacity building of fisheries and aquaculture line management agencies to take on disaster preparedness and response responsibilities;
- providing technical expertise on fisheries issues to key agencies responsible for disaster relief;

- supporting strategic post-disaster rehabilitation actions that improve the adaptive capabilities of fisheries and aquaculture infrastructure that may have been damaged;
- investing in weather information and storm warning systems; and
- addressing conflicts and synergies presented by adaptation strategies for different sectors in a holistic manner.

Adaptation through livelihood diversification

Countries and communities that are dependent on the fisheries and aquaculture sectors may be vulnerable to climate and market driven changes. Supporting greater flexibility in livelihood strategies through building the livelihood asset base will buffer the impacts of climate change on people's livelihoods (Badjeck *et al.* 2009). For instance, pursuing mixed livelihood strategies with different activities that vary in their climate response and sensitivity will be important for aquaculture-dependent livelihoods as well as capture fisheries-dependent livelihoods (Allison *et al.* 2007). Decision-makers can learn much from previous and existing approaches to livelihood diversification in response to stressors such as extreme events. For instance, responses in the form of seasonal and/or permanent migration can be facilitated or managed through specific policy interventions (Badjeck *et al.* 2009).

> ***Ensure that the opportunities and threats presented by climate change are understood and supported as part of adaptation measures for the sector***
>
> Identify the winners and the losers in the fisheries sector. For instance, any geographical shifts in productivity should be identified and supported strategically; supporting the losers to diversify or exit the sector and the winners to capitalize more effectively on new opportunities.

Adaptation through reduction of vulnerability: a "no-regret" strategy

Practical approaches to adapting to climate change can be made by addressing the fundamental problems of fisheries management (or production risks in aquaculture) and the underlying factors that cause vulnerabilities to producers. Increasing the resilience of communities engaged in fishing and aquaculture enables them to absorb disturbances and reorganize themselves following perturbation, while still delivering benefits for poverty reduction. This involves investment through:

- specific training and organization, such as risk-reduction and reduction of exposure;
- transfer initiatives such as early warning systems, storm-shelters, managed retreat and insurance, disease reporting, extension and safety training; and
- reducing sensitivity (e.g. Allison *et al.* 2007), including diversification of livelihood and decreasing dependency on fisheries or aquaculture.

> ***High-risk countries and locations should be identified and supported***
>
> Understanding which countries and localities in the region will be most sensitive to climate change related changes to the fisheries sector needs to be improved. High-risk countries should be targeted and supported explicitly to tackle threats to the fisheries sector.

The "no-regret" strategy should also consider that the positive and effective involvement of women can greatly increase the impact of vulnerability reduction. Women are powerful agents of change and can help or hinder in dealing with many relevant issues such as energy consumption, deforestation, burning vegetation, population growth and economic decision-making (IUCN 2007).

Adapting to positive opportunities presented by climate change

Negative impacts are extensively presented in the literature whereas positive impacts of climate variability and change on the fisheries sector are not duly highlighted. The impacts of climate change will not be distributed equally. There will be winners and losers, and some communities may suffer significant losses as a result of physical damages or changes in fish distribution, whereas others will be less affected—or may even benefit from, for instance, positive changes in the abundance of certain species. Successful identification of policies that enhance adaptation will only occur if the opportunities brought by climate change are identified.

In certain localities, capture fisheries and aquaculture operations may be advantaged by climate change related impacts, providing new opportunities for those both within and outside the sector. For instance, inland flooding may create new habitats for freshwater capture and aquaculture operations and the local displacements of stocks may present fishing opportunities in new locations (Daw *et al.* 2009).

Diversification of aquaculture production

In addition to pursuing a strategy of general livelihood diversification, particularly for communities involved in small-scale aquaculture, there is great scope for the diversification of aquaculture operations as an adaptive strategy through increasing the number of species being cultured. This can provide a form of insurance for difficult to predict climate change scenarios and/or local climate change impacts, particularly with regard to events such as disease outbreaks or market shifts (De Silva and Soto 2009).

It is possible that mariculture may present valuable opportunities as an adaptive livelihood strategy in Asia for coastal communities based on agricultural practices that may become unviable because of sea level rise and salinization, presenting a relatively reliable way of securing protein in situations where freshwater may become less available (De Silva and Soto 2009). This indicates that livelihood security in areas vulnerable to a decrease in agricultural productivity should be supported to diversify their livelihoods away from increasingly unviable agricultural activities, requiring investment in supporting communities to branch into aquaculture. This would require greater cross-sectoral coordination to ensure policy coherence. For instance, policies aimed at promoting food security with a narrow focus on grain crops that prohibit the conversion of rice fields into fish ponds (Edwards 2000); integrating fisheries more effectively into the broader debate on food security is therefore an important step.

Management of capture fisheries stocks in response to climate change and catch declines

Fisheries managers may need to remove pressure on stocks to support the long-term sustainability of fisheries; stocks that are not overfished are more likely to have greater resilience to climate change impacts. It is also likely that certain species and stocks will be impacted more than others, requiring a corresponding reduction in fishing efforts. Actions may include improving fisheries management and enforcement regimes as well as enabling exit from affected fisheries in response to declines – this would require corresponding re-training and re-employment efforts (McFadyen and Allison 2009).

Economic and market diversification

In a climate changed future where food and energy security may pit the feed demands of the fisheries and aquaculture industry against other sectors (e.g. agriculture, water, biofuel) moving the sectors towards more sustainable, less resource-demanding, and/or less climate-sensitive species and diversifying cultured species may be important. Any changes in the direction of supply chains, whether through switching to more viable capture fisheries stocks, the diversification of species used in aquaculture operations, or technological innovations in different breeds, will require substantial corresponding changes in consumer and market demands (De Silva and Soto 2009). This could be supported through targeted policies to support changes in production patterns but may also require consumption changes in countries where market demand originates or require the creation of new markets.

Build supportive economic and trade policies

Given the considerable role of the sector in trade and export for the Asia region, changes in production patterns and trade opportunities will need corresponding changes in economic and trade policies. Product and export diversification should be pursued as part of this.

Insurance for the fisheries and aquaculture sector

Insurance can help to strengthen financial systems to withstand shocks and allow the spread and transfer of risk. Analyses towards the development of insurance systems will also provide countries with risk and loss quantifications (McFadyen and Allison 2009). At the livelihood-level, private or public insurance will prevent the disruption caused by a lack of access to credit for re-building purposes after negative events

(Badjeck *et al.* 2009). It is suggested that insurance cover for aquaculture operations will be an important adaptive measure, particularly for the Asian region (Secretan *et al.* 2007). Through requiring mandatory insurance for operations over a certain size, governments could help to buffer the industry from bankruptcies caused by extreme events, potentially buffering economies (De Silva and Soto 2009). Developing appropriate insurance systems could be carried out with strategic engagement with the private sector.

Technological approaches to adaptation in the aquaculture sector

Technological solutions may be able to provide answers to some of the problems faced by the aquaculture sector. Equipment and energy intensive technological innovations, such as the use of re-circulation systems to reduce freshwater requirements, may tend to be too expensive to provide solutions for operations that are not built for luxury markets (Allison *et al.* 2007) but there are many other types of technological interventions that can be pursued. Selective fish breeding and the selection of more appropriate species and breeds is another adaptive approach that should be supported. This could involve investment in breeds and species that have different optimal thermal thresholds, feed conversion efficiencies, growth characteristics and disease tolerance (Allison *et al.* 2007, De Silva and Soto 2009). For instance, De Silva and Soto (2009) note that omnivorous and filter feeding finfish aquaculture should be promoted in the tropics and subtropics.

Promote appropriate technologies

Changing conditions will necessitate investing in and adopting new technologies. For certain subsectors, such as aquaculture, this will be of crucial importance. A great deal of this knowledge and technology may be locally available and small-scale technologies should not be over-looked.

Fisheries and aquaculture contribution to climate change mitigation

Of the global total of fossil fuels burnt annually, the capture fisheries sector contributes only around 1.2 percent (Tyedmeyers *et al.* 2005). Large fishing vessels contribute the bulk of these emissions and the global contribution of this group to emissions is about 8.5 percent of all emissions derived from the shipping industry (Eyring *et al.* 2005). There are few studies examining the specific role of Asia in this, but it is likely that Asia's contribution to this total is relatively small compared to the contribution of industrialized, Northern countries.

Mitigation actions may provide opportunities for the fisheries sector. For instance payment for ecosystem services schemes targeting ecosystems associated with fisheries systems could bring financial benefits that could be funnelled back into the sector.

Interest in marketing carbon from forests is increasing, but markets for other environmental services are yet to develop. Some existing opportunities include initiatives on Reducing Emissions from Deforestation and Forest Degradation (REDD) under the UNFCCC process as well as revenues from ecotourism. The *design of such financial mechanisms to implement mitigation needs to take into consideration the fishery sector, which has been ignored up until now.* Mangroves contain large amounts of carbon and have high sequestration rates in comparison with other forest types and land uses. A high proportion of the carbon is contained in the soil and this is released if mangroves are converted. There are three ways to realize the value of carbon in forests.

- Clean Development Mechanism (CDM) of the Kyoto Protocol;
- voluntary carbon markets; and
- corporate support (carbon offsetting).

Mitigation opportunities associated with the sector could also serve the goals of good fisheries management

Asia's contribution to emissions via the fisheries sector is considered to be relatively low, and thus there is unlikely to be a strong of emphasis on the sector in emission mitigation efforts. However, improved energy efficiency could complement other positive fisheries management goals for the sector (e.g. reductions in fleet capacities, removal of perverse fuel subsidies).

Good management of ecosystems crucial to fisheries systems (e.g. salt marshes, seagrass beds, mangroves) can also provide the benefit of maintaining systems efficient in sequestering carbon. Through actively pursuing mitigation activities, the sector could potentially generate revenue to fund adaptation actions.

Some key considerations that influence how viable this will be is that compliance mechanisms (CDM under the Kyoto Protocol) only allow for afforestation and reforestation and not REDD activities at present. Importantly, changes to hydrology are not allowed (e.g. reforestation of abandoned fish ponds). CDM does not include soil carbon for small projects (<16 000 tonnes $CO_2 yr^{-1}$).

The Voluntary Carbon Standard is the best recognized of the voluntary standards and carbon credits verified under the VCS fetch higher prices than the CDM Temporary Certified Emission Reductions (tCERs). Validation of VCS is simpler than CDM and soil carbon can be included in small projects. The peat rewetting methodology will be available soon and so projects will be allowed to make hydrological changes that are currently ineligible. Prospective opportunities are therefore:

– projects in threatened degraded mangrove areas with deep soils – these should generate most carbon credits;
– projects on abandoned fish ponds – these may also generate a large number of credits; and
– projects in large areas of mangroves – these will reduce start-up and administration costs per unit area.

It is important to note that currently, the value of carbon credits is less than US$150 per hectare per year even under the best conditions. Practically, this value will probably be significantly less as, under VCS, up to 60 percent of credits may need to be kept in a "buffer" depending on assessed risk (10 percent of the "buffer" is released every five years if risk is proved to be low). The transaction costs of setting up an institutional mechanism and distributing benefits to fisher folk also needs to be considered as validation and registration costs are very high (US$160 000 + US$14 000 every five years for verification). The policy and legislative support, and carbon credit ownership should be clarified with relevant agencies and methodologies will need to be refined and evidence provided for the number of credits a particular project is claiming.

There are also practical technically focused innovations in fisheries to reduce fuel usage and emissions. These would cover improvements to fishing vessels (e.g. more efficient vessel design reducing engine size requirements) and fishing methods (e.g. static methods rather than the use of active gear such as trawling with high energy requirements). Some of these changes could be incentives through policy or fiscal measures such as differential licensing conditions and/or financial incentives for vessel decommissioning.

In their review of aquaculture's contribution to climate change, De Silva and Soto (2009) note that emissions depend on the type of operation. For instance, carnivorous finfish and shrimp farming operations consume more energy than comparable animal husbandry operations (e.g. chicken, lamb or beef production). However, it is highlighted in the report that these forms of aquaculture account for less than 10 percent of global aquaculture production, and the energy consumption of aquaculture operations focusing on omnivorous finfish, bivalves and seaweed is comparatively lower than animal husbandry operations. There are opportunities through the adoption of low impact aquaculture systems:

– seaweed culture could potentially contribute to mitigating climate change through its potential as a biofuel; and
– herbivorous aquaculture species may have a lower carbon footprint than carnivorous species and if so could be an ideal replacement for them.

Improvements related to the transportation of fish to markets and innovations in fish processing/ transport might cover improved building design and handling practices to reduce energy requirements and increase energy efficiency (e.g. through better insulation in ice plants, freezing plants, cold stores and chill stores). Other possible positive opportunities may include branding and certification initiatives to promote energy efficient products (McFadyen and Allison 2009). There may also be important opportunities in carbon trapping in aquaculture ponds, which if well managed present a large opportunity for Asia (Bunting and Pretty 2007).

Impacts of other sectors' mitigation and adaptation on fisheries and aquaculture

Another important consideration is that the mitigation and adaptation strategies of other sectors may have direct impacts on fisheries and aquaculture (FAO 2008b).

- Alternative energy:
  - use of coastal areas for wind and wave power may limit fishing or aquaculture areas, or impact critical habitats;
  - increasing the number of hydropower large dams would cause disruptions to spawning migrations and larval fish flows and erratic water releases from hydropower dams would result in destruction of fishing gears as well as injury and loss of life; and
  - biofuel production may affect prices of feeds for aquaculture.
- Agricultural transformations:
  - changing water flows and abstraction demands by agriculture may affect rivers and consequently fisheries;
  - flood controls and irrigation development are known to impact fisheries; and
  - water saving strategies for rice production will limit the available water in rice fields for wild fish production.

Investment in research and planning

Research is necessary to support appropriate, knowledge-based adaptation strategies. There is a need for research specific to the Asia region to analyse potential local and regional responses. Modelling exercises to understand climate change impacts and the potential ecophysical and socio-economic repercussions of this could be key in guiding policy-makers in key decisions (De Silva and Soto 2009). Existing research approaches could be applied to strengthen regionally specific models and inform policy-making. "Bioclimate envelope" analysis, for instance, is used to define the limits and interacting effects of key parameters (e.g. temperature, salinity, oxygen) on the performance and survival of species, and this could be used to model changes in distribution, abundance and species composition (Barange and Perry 2009). Incorporating cross-sectoral analyses into these would be essential to make important choices regarding the allocation of resources to different sectors based on the predicted viability of different livelihood options. For example, through understanding potential patterns of saline intrusion, shifts in land use from agriculture to aquaculture can be pursued.

Research and planning priorities could include the following (McFadyen and Allison 2009):

- climate change impact and risk assessments at the local and national levels, including more effective assessments of physical impacts of climate change on fisheries and aquaculture systems, as well as associated ecosystems at time-scales relevant to sectoral planning (e.g. to 2030 as well as to 2050 and 2100);
- development of more accurate fisheries and aquaculture specific indicators of exposure, dependency and adaptive capacity, to inform sector- and country-specific vulnerability analyses; research into sector-specific mitigating possibilities (e.g. sector-specific carbon accounting methodologies; identification of critical carbon-costly links in global value chains in aquaculture and fishery products;
- identification of new sector-specific adaptive measures and better information on the technical and political feasibility of those already identified;
- the technical and socio-economic viability of mitigation options such as carbon sequestration by aquatic ecosystems and energy efficiency (Badjeck *et al.* 2009);
- research on the potential costs of adaptation and mitigation initiatives complemented by analyses of funding opportunities; and
- identifying the positive opportunities presented by climate change in specific countries and localities (Badjeck *et al.* 2009).

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ASIA-PACIFIC FISHERY COMMISSION
FAO Regional Office for Asia and the Pacific
39 Phra Athit Road, Bangkok, Thailand
www.apfic.org

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