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Climate change implications for fisheries and aquaculture

Overview of current scientific knowledge

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Preparation of this document

This document was prepared in response to the request from the twenty-seventh session of the Committee on Fisheries (COFI) that the FAO Fisheries and Aquaculture Department (FI) should undertake a scoping study to identify the key issues on climate change and fisheries. It contains the three comprehensive technical papers that formed the basis for the technical discussions during the Expert Workshop on Climate Change Implications for Fisheries and Aquaculture held from 7 to 9 April 2008 at FAO headquarters. The conclusions and recommendation of this Expert Workshop are available in the 2008 FAO Fisheries Report No. 870.

The three papers in this document intend to provide an overview of the current available knowledge on the possible impacts of climate change on fisheries and aquaculture. The first addresses climate variability and change and their physical and ecological consequences on marine and freshwater environments. The second tackles the consequences of climate change impacts on fishers and their communities and reviews possible adaptation and mitigation measures that could be implemented. Finally, the third addresses specifically the impacts of climate change on aquaculture and reviews possible adaptation and mitigation measures that could be implemented.

All participants in the Expert Workshop are gratefully acknowledged for providing comments and helping to improve the three technical papers included in this publication.

Funding for the organization of the Expert Workshop and the publication of this Technical Paper was provided by the Governments of Italy and Norway through activities related to the FAO High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy (Rome, 3–5 June 2008).

Abstract

An overview of the current scientific knowledge available on climate change implications for fisheries and aquaculture is provided through three technical papers that were presented and discussed during the Expert Workshop on Climate Change Implications for Fisheries and Aquaculture (Rome, 7–9 April 2008). A summary of the workshop outcomes as well as key messages on impacts of climate change on aquatic ecosystems and on fisheries- and aquaculture-based livelihoods are provided in the introduction of this Technical Paper.

The first paper reviews the physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. The paper begins with a review of the physical impacts of climate change on marine and freshwater systems and then connects these changes with observed effects on fish production processes. It also outlines a series of scenarios of climate change impacts on fish production and ecosystems through case studies in different regions and ecosystems.

The second paper tackles the consequences of climate change impacts on fisheries and their dependent communities. It analyses the exposure, sensitivity and vulnerability of fisheries to climate change and presents examples of adaptive mechanisms currently used in the sector. The contribution of fisheries to greenhouse gas emissions is addressed and examples of mitigation strategies are given. The role of public policy and institutions in promoting climate change adaptation and mitigation is also explored.

Finally, the third paper addresses the impacts of climate change on aquaculture. It provides an overview of the current food fish and aquaculture production and a synthesis of existing studies on climate change effects on aquaculture and fisheries. The paper focuses on the direct and indirect impacts of climate change on aquaculture, in terms of biodiversity, fish disease and fishmeal. Contribution of aquaculture to climate change is addressed (carbon emission and carbon sequestration), as well as possible adaptation and mitigation measures that could be implemented.

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Contents

Climate change and capture fisheries: potential impacts, adaptation and mitigation

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ABSTRACT

Climate change is predicted to have a range of direct and indirect impacts on marine and freshwater capture fisheries, with implications for fisheries-dependent economies, coastal communities and fisherfolk. This technical paper reviews these predicted impacts, and introduces and applies the concepts of vulnerability, adaptation and adaptive capacity.

Capture fisheries are largely driven by fossil fuels and so contribute to greenhouse gas emissions through fishing operations, estimated at 40-130 Tg CO_2. Transportation of catches is another source of emissions, which are uncertain due to modes and distances of transportation but may exceed those from fishing operations. Mitigation measures may impact on fisheries by increasing the cost of fossil fuel use.

Fisheries and fisherfolk may be impacted in a wide range of ways due to climate change. These include biophysical impacts on the distribution or productivity of marine and freshwater fish stocks through processes such as ocean acidification, habitat damage, changes in oceanography, disruption to precipitation and freshwater availability. Fisheries will also be exposed to a diverse range of direct and indirect climate impacts, including displacement and migration of human populations; impacts on coastal communities and infrastructure due to sea level rise; and changes in the frequency, distribution or intensity of tropical storms. Fisheries are dynamic social-ecological systems and are already experiencing rapid change in markets, exploitation and governance, ensuring a constantly developing context for future climate-related impacts. These existing socioeconomic trends and the indirect effects of climate change may interact with, amplify or even overwhelm biophysical impacts on fish ecology. The variety of different impact mechanisms, complex interactions between social, ecological and economic systems, and

the possibility of sudden and surprising changes make future effects of climate change on fisheries difficult to predict.

The vulnerability of fisheries and fishing communities depends on their exposure and sensitivity to change, but also on the ability of individuals or systems to anticipate and adapt. This adaptive capacity relies on various assets and can be constrained by culture or marginalization. Vulnerability varies between countries and communities, and between demographic groups within society. Generally, poorer and less empowered countries and individuals are more vulnerable to climate impacts, and the vulnerability of fisheries is likely to be higher where they already suffer from overexploitation or overcapacity.

Adaptation to climate impacts includes reactive or anticipatory actions by individuals or public institutions. These range from abandoning fisheries altogether for alternative occupations, to developing insurance and warning systems and changing fishing operations. Governance of fisheries affects the range of adaptation options available and will need to be flexible enough to account for changes in stock distribution and abundance. Governance aimed towards equitable and sustainable fisheries, accepting inherent uncertainty, and based on an ecosystem approach, as currently advocated, is thought to generally improve the adaptive capacity of fisheries. However, adaptation may be costly and limited in scope, so that mitigation of emissions to minimise climate change remain a key responsibility of governments.

ACKNOWLEDGEMENTS

This report was compiled with input from Eddie Allison from the WorldFish Center, Penang, and benefited from the comments of participants at the FAO Workshop on Climate Change Implications for Fisheries and Aquaculture held in Rome from 7 to 9 April 2008. Cassandra De Young also provided comments which improved the report.

CONTENTS

KEY MESSAGES

1. Food security in fishing communities will be affected by climate change through multiple channels, including movement of people to coasts, impacts on coastal infrastructure and living space and through more readily observed biophysical pathways of altered fisheries productivity and availability. Indirect changes and trends may interact with, amplify or even overwhelm biophysical impacts on fish ecology.
2. Non-climate issues and trends, for example changes in markets, demographics, overexploitation and governance regimes, are likely to have a greater effect on fisheries in the short term than climate change.
3. The capacity to adapt to climate change is unevenly distributed across and within fishing communities. It is determined partly by material resources but also by networks, technologies and appropriate governance structures. Patterns of vulnerability of fisher folk to climate change are determined both by this capacity to adapt to change and by the observed and future changes to ecosystems and fisheries productivity.
4. Building adaptive capacity can reduce vulnerability to a wide variety of impacts, many of them unpredictable or unforeseen. The key role for government intervention is to facilitate adaptive capacity within vulnerable communities.
5. There is a wide range of potential adaptation options for fisheries, but considerable constraints on their implementation for the actors involved, even where the benefits are significant. For government interventions there may be trade-offs between efficiency, targeting the most vulnerable and building resilience of the system.

1. INTRODUCTION

1.1 Fisheries' contribution to food security

Fish is highly nutritious, so even small quantities can improve people's diets (FAO, 2007a). They can provide vital nutrients absent in typical starchy staples which dominate poor people's diets (FAO, 2005a). Fish provides about 20 percent of animal protein intake (Thorpe *et al*., 2006) in 127 developing countries and this can reach 90 percent in Small Island Developing States (SIDS) or coastal areas (FAO, 2005a). Although aquaculture has been contributing an increasingly significant proportion of fish over recent decades, approximately two-thirds of fish are still caught in capture fisheries.[1]

Fisheries can also contribute indirectly to food security by providing revenue for food-deficient countries to purchase food. Fish exports from low-income, food-deficient countries is equivalent to 50 percent of the cost of their food imports (FAO, 2005a).

1.2 Fisheries' contribution to livelihoods and economic development

The number of people directly employed in fisheries and aquaculture is conservatively estimated at 43.5 million, of which over 90 percent are small-scale fishers (FAO, 2005a). In addition to those directly employed in fishing, there are "forward linkages" to other economic activities generated by the supply of fish (trade, processing, transport, retail, etc.) and "backward linkages" to supporting activities (boat building, net making, engine manufacture and repair, supply of services to fishermen and fuel to fishing boats, etc.). Taking into account these other activities, over 200 million people are thought to be dependent on small-scale fishing in developing countries, in addition to millions for whom fisheries provide a supplemental income (FAO, 2005a). Fisheries are often available in remote and rural areas where other economic activities are limited and can thus be important engines for economic growth and livelihoods in rural areas with few other economic activities (FAO, 2005a). Some fishers are specialized and rely entirely on fisheries for their livelihood, while for many others, especially in inland fisheries and developing countries, fisheries form part of a diversified livelihood strategy (Allison and Ellis, 2001; Smith, Nguyen Khoa and Lorenzen, 2005). Fisheries may serve as a "safety net" to landless poor or in the event of other livelihoods failing (FAO 2005a).

Many small-scale fisher folk live in poverty, often understood as resulting from degradation of resources and/or from the safety net function of fisheries' for the poorest in society. This generalised understanding of the economic poverty of fishers in the developing world captures some of the situation of small scale fishers, but misses both the fact that they may earn more than peers in their communities and that their poverty is multidimensional and related to their vulnerability to a variety of stressors including HIV/AIDS, political marginalization and poor access to central services and healthcare (Bene, 2003; FAO, 2005a). Small-scale fisheries, and especially inland fisheries, have also often been marginalized and poorly recognized in terms of contribution to food security and poverty reduction.

1.3 Current trends and status of fisheries

Climate change impacts on fisheries will occur in the context of, and interact with existing drivers, trends and status of fisheries.

Following rapid increases in production since the 1950s, the yield of global fish has stagnated and may be declining. Many stocks have been, or are at risk of being, overexploited (Hilborn *et al*., 2003; FAO, 2005b). Statistics from the Food and

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[1] Capture fisheries provide 50 percent of fish for food production and 58 percent of total fishery production, which includes marine mammals, crocodiles, corals, sponges, shells and aquatic plants (FAO, 2009).

Agriculture Organization of the United Nations (FAO) support this view, reporting that marine fisheries production peaked in the 1980s and that over recent years, approximately half of fisheries have been exploited to their maximum capacity, one quarter overexploited, collapsed or in decline and only one quarter have had potential for increased production (FAO, 2007a).

Inland fisheries have increased throughout the last half century reaching about nine million tonnes in 2002, although this trend has been accompanied in many lake and river systems by overfishing and the collapse of individual large, valuable species. "Ecosystem overfishing" has occurred as the species assemblage is fished down and fisheries use smaller nets to catch smaller and less valuable species (Allan *et al.,* 2005). Inland fish stocks have also been aversely affected by pollution, habitat alteration, infrastructure (dams and water management schemes) and introduction of alien species and cultured fish (Allan *et al.,* 2005).

In addition to stock collapses, overfishing in general has reduced revenues and economic efficiency, increased variability and reduced the resilience of stocks and catches (Hsieh *et al*., 2006). The aquatic ecosystems have been profoundly altered by fishing, with a generalised trend of "fishing down the food web" as fish from higher trophic levels decline, leading to lower trophic levels of harvests (Pauly *et al.,* 1998; Allan *et al.,* 2005) and a range of ecosystem effects, including disturbance of sensitive habitats by destructive gears such as explosives, poisons and heavy bottom trawling equipment. Extinctions of target fish species, even marine species with high reproductive outputs, are now thought to be possible (Sadovy and Cheung, 2003) while impacts on incidentally caught species and habitats also constitute a loss of aquatic biodiversity (Worm *et al.,* 2006; Allan, 2005) and can impact ecological processes like predation (Myers *et al.,* 2007), bioerosion (Bellwood, Hoey, and Choat, 2003), provision of food to seabirds (Jahncke, Checkley and Hunt, 2004) and transport of nutrients (Allan *et al.,* 2005). By introducing a new and dominant selection pressure, fishing probably also affects the genetic character of fish stocks (Hutchings, 2000).

Many industrialized fisheries suffer from over-investment and surplus fishing capacity (Hilborn *et al.,* 2003) making it economically and politically difficult to scale back fishing to match biological productivity (Ludwig, Hilborn and Walters, 1993). Thus, even without any changes attributable to climate change, there is a generally perceived need to reduce fishing capacity and fishing effort in most fisheries.

High profile collapses of Peruvian anchovy stocks, the Northwest Atlantic cod and sea cucumber fisheries throughout the tropical Indian and Pacific oceans are emblematic cases of the failure of fisheries management (in the former cases, in spite of considerable investments in scientific research) and the difficulty of sustainably exploiting many stocks. There is a growing awareness of the importance of understanding human aspects of fisheries and focusing on fisheries governance rather than purely management. Much more attention is now being paid to incentives created by management measures and institutional arrangements around fisheries, including the incorporation of local fishers and their knowledge through co-management and community-based management initiatives (Jentoft, 2006; Hilborn, 2003). This trend has been accompanied by a greater awareness of the importance of taking account of ecosystems within which fisheries are embedded. Both the involvement of stakeholders and the need to consider the wider ecosystem are incorporated in the Ecosystem Approach to Fisheries (FAO, 2003a).

Another key trend in the nature of fisheries is their increasing commercialization and globalization. Even small-scale fisheries are usually to some extent commercial, involving the sale of at least some of the catch (Berkes *et al.,* 2001). Meanwhile, international trade in fisheries products increased sharply until the 1990s. Forty percent of the total value and 33 percent of the total volume of fish produced is traded internationally. Of this, about half is exported from developing countries (Delgado *et al.,* 2003) earning them greater export revenues than any other food commodity (Thorpe *et al*., 2006). In the case of specific high value fisheries like sea urchins or live reef fish, demand from markets on the other side of the world can influence fishers in remote areas and result in rapid development, overexploitation and collapse of fisheries within a matter of years (Berkes *et al.,* 2006; Scales *et al.,* 2005).

1.4 The exposure and sensitivity of fisheries to climate change

Marine and freshwater fisheries are susceptible to a wide range of climate change impacts. The ecological systems which support fisheries are already known to be sensitive to climate variability. For example, in 2007, the International Panel on Climate Change (IPCC) highlighted various risks to aquatic systems from climate change, including loss of coastal wetlands, coral bleaching and changes in the distribution and timing of fresh water flows, and acknowledged the uncertain effect of acidification of oceanic waters which is predicted to have profound impacts on marine ecosystems (Orr *et al.,* 2005). Meanwhile, the human side of fisheries: fisher folk, fishing communities and related industries are concentrated in coastal or low lying zones which are increasingly at risk from sea level rise, extreme weather events and a wide range of human pressures (Nicholls *et al.,* 2007a). While poverty in fishing communities or other forms of marginalization reduces their ability to adapt and respond to change, increasingly globalized fish markets are creating new vulnerabilities to market disruptions which may result from climate change.

A key feature of the socio-economics of inland fisheries, which may influence how they interact with climate change, is the intense seasonality of many highly productive floodplain fisheries, for example those in Southeast Asia (SEA) and Bangladesh (Dixon *et al*., 2003). Somewhat related to this trend is the tendency for inland fisheries to be conducted by people who do not define themselves as fishers, but rather engage with seasonal fisheries alongside other livelihood options (Smith *et al.,* 2005).

The physical and ecological impacts of climate change and their relevance to the marine and freshwater environments are the focus of Barange and Perry in chapter one; this paper focuses on the impacts of those pathways on fishers and their communities. Allison *et al.* (2005) conducted a comprehensive review of potential climate change impacts on capture fisheries. This report draws on examples from Allison *et al. (*2005), but aims to focus on new findings, additional impact pathways and issues that have subsequently been raised.

2. CONCEPTUAL FRAMEWORKS

2.1 Fisheries categories

Fisheries demonstrate wide diversity in terms of scale, environment, species, technology, markets, fishers, management arrangements and political contexts (Berkes *et al.,* 2001; Jennings, Kaiser and Reynolds, 2001) and these factors will determine how each is affected by climate change. To simplify this diversity, a generalization will be made between large-scale/industrialized and small-scale/artisanal fisheries. Some of their characteristics relevant to the issue of climate change are illustrated in Table 1. Small-scale fisheries employ more than 99 percent of fishers but produce approximately 50 percent of global seafood catches.

Fisheries for reduction to fishmeal and fish oil are clearly distinguishable from fisheries for food production as they are subject to different market dynamics and have different implications for society.

Inland freshwater fisheries will be distinguished from marine fisheries. Inland fisheries are based on very different biophysical systems to marine fisheries, but in this paper, which focuses on the impacts of climate change on fisher folk rather than biophysical mechanisms, much of the discussion of vulnerability and poverty will be

TABLE 1
Some generalized differences between large-scale and small-scale fisheries

Characteristic	Large-scale, industrial fisheries	Small-scale, artisanal fisheries
Perpetrated by	Mostly developed countries	Mostly developing countries
Found in	Mostly marine (often oceanic) waters	Near-shore marine and inland waters
Vessels and equipment	Mechanised, advanced technology, possess distant water-fleet not limited to local waters	Manual, simple technology, fishing limited to local waters
Vessels and equipment	Mechanised, advanced technology	Manual, simple technology
Use of fuel	High (14 to19 million tonnes, 2 to 5 tonnes fish/t fuel oil)	Low (1 to 2.5 million tonnes, 2 to 5 tonnes fish/t fuel oil)
Use of catch	High value international markets for food and reduction to fishmeal	For food, mostly local, but increasingly global high-value
Direct employment	~500 000 fishers	~50 000 000 fishers
Catches per man hour	High	Low
Fishers	Full-time, professional, income often high relative to society	Full and part time, often poor
Complexity of fishery	Low, fewer fishing units, similar gear, few species	High, more fishing units and diverse gear, many species
Management capacity	High, large management bureaucracies, extensive scientific attention and capacity	Low, fishing communities remote from government, limited or no scientific information available

Sources: after Berkes *et al.,* 2001; Pauly, 2006; and Baelde, 2007.

relevant to small-scale marine fisheries as well as inland fisheries (which are generally small-scale in nature).

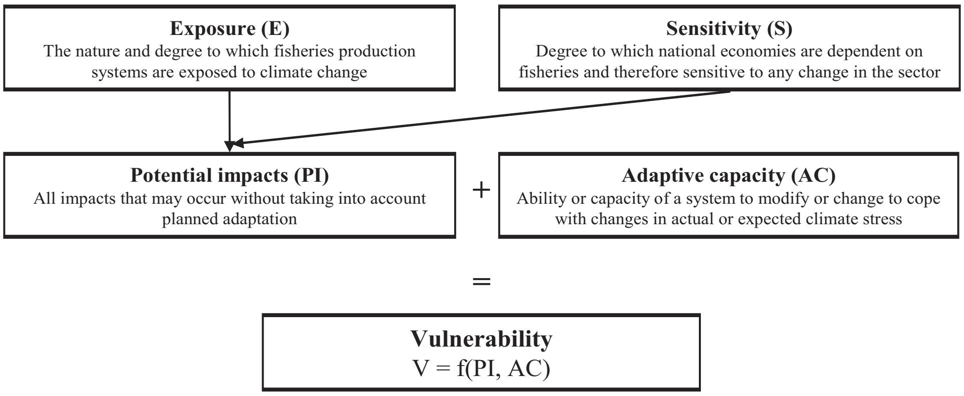
2.2 Vulnerability and resilience

Vulnerability has become a key concept in the climate change literature. It is defined as the susceptibility of groups or individuals to harm as a result of climatic changes. Vulnerability is often compounded by other stresses and recognizes that the way in which people and systems are affected by climate change is determined by external environmental threats, internal factors determining the impact of those threats and how systems and individuals dynamically respond to changes. The Intergovernmental Panel on Climate Change definition of vulnerability is "…a function of the character, magnitude, and rate of climatic variation to which a system is exposed, its sensitivity, and its adaptive capacity." (McCarthy *et al.,* 2001: p. 995). These elements are described in Figure 1, which clarifies the important distinction between impacts and vulnerabilities.

The vulnerability of an individual, community or larger social group depends on its capacity to respond to external stresses that may come from environmental variability or from change imposed by economic or social forces outside the local domain. Vulnerability is complex and depends on a combination of natural and socio-political attributes and geography. Non-climate factors such as poverty, inequality, food insecurity, conflict, disease and globalization can increase vulnerability by affecting the exposure, sensitivity and adaptive capacity of systems, communities and individuals (Adger *et al.,* 2007).

Resilience is a concept that is related to vulnerability and adaptive capacity. It has increasingly been applied to the management of linked social-ecological systems (SES) such as fisheries. Resilience is usually applied with an explicit recognition that SES are "complex systems" resulting in uncertain and surprising behaviours including path dependence, alternative stable states, thresholds and periods of apparent stability punctuated by rapid shifts to qualitatively different behaviours. A resilience perspective does not focus on the ability of a system to resist change. Instead it emphasises the importance of disturbance, reorganization and renewal. The dynamic nature of the concept makes it useful when considering uncertain effects of climate change on complex systems like fisheries. Social-ecological resilience includes the importance of social learning, knowledge systems, leadership, social networks and institutions for

FIGURE 1
Conceptual model of vulnerability



Source: adapted from Allison *et al.,* 2005.
Note: The word "system" can be interpreted as country, region, community, sector, social group or individual.

navigating disturbance, adapting to change and managing the resilience of a system to remain in a desirable state (Folke, 2006). Accordingly, resilience is seen as the capacity of a system to absorb disturbance while maintaining its basic functions, to self-organise and to build capacity for learning. Resilience of aquatic production in the developing world has been defined as the ability to "absorb shocks and reorganise… following stresses and disturbance while still delivering benefits for poverty reduction." (Allison, Andrew and Oliver, 2007.)

2.3 Fisheries, poverty, livelihoods and the socio-economic context of fisheries

The poverty of many fishing communities has conventionally been understood as deriving endogenously because of the inevitable overexploitation and poor returns from open-access resources (people are poor because they are fishers); or exogenously because the influx of the poorest of the poor into fisheries as a last resort (they are fishers because they are poor) (Bene, 2003). However, both Bene (2003) and Smith, Nguyen Khoa and Lorenzen (2005) suggest that this view is over simplistic and small-scale fisheries need to be understood within their wider socio-economic and cultural context. Both authors draw on Allison and Ellis (2001) who introduced the analytical framework of the sustainable livelihoods approach to explicitly detail aspects of small-scale fisheries that should be considered.

A livelihood can be defined as the capabilities, assets and activities required for means of living (Chambers and Conway, 1992). The concept of sustainable livelihood seeks to bring together the critical factors, assets and activities that affect the vulnerability or strength of household strategies (Allison and Ellis, 2001; Ellis, 2000). People can access, build and draw upon five types of capital assets: human, natural, financial, social and physical (Box 1).

Access to assets is mediated by policies, institutions or processes (PIPs) such as market or organizations (see Figure 2). Livelihoods are also affected by a vulnerability context which includes, for instance, seasonality and changes in fuel prices (Allison and Horemans, 2006).

This framework and the perspective of fisheries being only one of a variety of sectors which individuals, households or communities draw on for their livelihoods (as is the case in many small-scale and inland fisheries, Smith, 2005) helps to understand some of the linkages of fisheries with wider systems and emphasises the importance of context. This leads to a more holistic analysis of fisheries and climate change because it sees fisheries, not as a simple relationship between a community and an aquatic

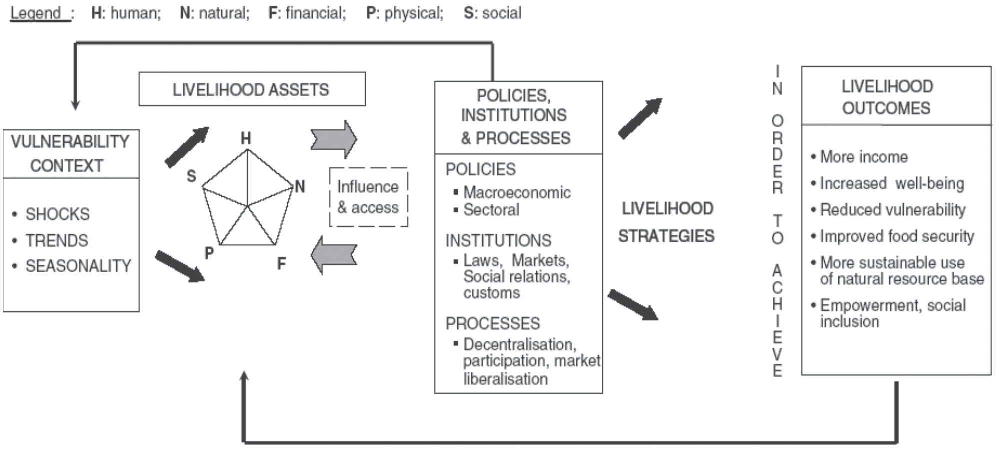
BOX 1

Livelihood assets identified by the sustainable livelihoods framework

Natural capital – the natural resource stocks (soil, water, air, genetic resources, etc.) and environmental services (hydrological cycle, pollution sinks, etc.) from which resource flows and services useful for livelihoods are derived.
Physical capital – physical assets comprise capital that is created by economic production processes. It refers to the basic infrastructure and producer goods needed to support livelihoods.
Economic or financial capital – the capital base (i.e. cash, credit/debt, savings and other economic assets) which are essential for the pursuit of any livelihood strategy.
Human capital – the skills, knowledge, ability to labour, good health and physical capability important for the successful pursuit of different livelihood strategies.
Social capital – the social resources (networks, social claims, social relations, affiliations, associations) upon which people draw when pursuing different livelihood strategies requiring coordinated actions.

FIGURE 2

The sustainable livelihoods framework



Source: after Allison and Horemans, 2006.
Note: Assets are indicated by letters: H: human, N: natural, F: financial, P: physical and S: social.

production system, but rather as part of a broader socio-economic system which is also affected by climate change. Climate change can be seen to impact each of the five types of assets (reviewed by Allison *et al*., 2005) as well as changing the vulnerability context and impacting on policies, institutions and processes.

2.4 Climate change and climate variability

Fisheries have always been affected by variable climate, including rare extreme events such as upwelling failures, hurricanes and flooding. Rather than a steady increase in temperature, climate change is likely to be experienced as an increased frequency of extreme events. Therefore, it is valid to analyse how fisheries react and adapt to existing climate fluctuations. This assumption, that future climate change will be manifested in the form of increasing severity of familiar phenomenon, may be appropriate to guide policy and actions for near-term climate impacts, but it should be borne in mind that thresholds, or "tipping points" may exist, which shift SES into qualitatively different conditions and present novel problems for fisheries sustainability and management.

2.5 Units and scales of analysis

Impacts of, vulnerability to, and adaptation to climate change can be examined for many different aspects of "fisheries" (e.g. sustainable fish production, well being, economies, food security and livelihoods) at a range of scales (e.g. nations, communities, sectors, fishing operations, households and individuals). Each of these aspects will be affected differently by climate change. For example, stopping fishing as an adaptation to reduced production would be viewed differently from a perspective of sustainable fish production compared to a perspective of the well-being of the communities involved. The scale of analysis can also affect findings. For example, national-level statistics might identify vulnerabilities of individual economies to certain impacts, but fail to discern vulnerable individuals or social groups within nations that are not highlighted as vulnerable by national statistics. This paper uses fisher folk and their communities as the main unit of analysis and examines vulnerability at a range of scales.

3. FISHERIES AND CLIMATE CHANGE MITIGATION

3.1 Fisheries' contribution to greenhouse gas emissions

Fisheries activities contribute to emissions of greenhouse gases (GHG), which are responsible for human-induced climate change, both during capture operations and subsequently during the transport, processing and storage of fish. Most work on fisheries' contribution to climate change has concluded that the minimal contribution of the sector to climate change does not warrant much focus on mitigation (Troadec, 2000), and there is limited information specific to fisheries on contributions to emissions. However, Tyedmers *et al.* (2005) calculate that fishing fleets consume the same quantity of oil as the whole of the Netherlands. This section discusses some of the emission pathways, potential mitigation measures, and examples.

3.1.1 Emissions from fisheries operations

Although most fisheries use vessels that are in some ways motorized and powered by fossil fuels, different types of fisheries use different fuels. Small fishing vessels use petrol or occasionally diesel in outboard and inboard engines, while medium-sized fishing vessels use diesel because it is less flammable than petrol. Only the very largest fishing vessels (more than 1 000 tonnes) use the most polluting heavy oil which fuels large freight vessels. This is because the heavy oil requires specialized equipment to treat it before it is passed to the engines (A. Smith, personal communication).

Current estimates suggest that aviation and the world shipping fleet, including commercial fisheries operations, contribute around the same amount of CO_2 emissions. In 2001 the 90 000 or so ships over 100 tonnes in the world fleet, consumed around 280 million tonnes of fuel, with emissions of around 813 Tg CO_2 and 21.4 Tg NO_x (a powerful GHG) in 2000 (Eyring *et al.,* 2005). There were around 23 000 fishing vessels and fish factory ships over 100 tonnes registered in 2001, making up 23 percent of the world's total fleet. Eyring et *al*., (2005) derive emission coefficients for these classes of vehicle, from which we estimate that total emissions from large fishing vessels is around 69.2 Tg CO_2 per annum, representing 8.5 percent of all shipping emissions. This estimate is midway between the higher estimate of Tyedmers, Watson and Pauly (2005), who used FAO catch statistics and typical fuel/catch efficiency for various fisheries to estimate fuel consumption of the global fishing fleet in 2000, and that of FAO (2007a) which analysed fuel oil use by fishing vessels in 2005 (Table 2).

The three estimates in Table 2 show substantial differences which, with the prospect of shipping being brought into emissions accounting systems, is an indication of the need for further research. Some of the differences may be explained by the different data

TABLE 2
Estimates of fuel consumption and CO_2 emissions from fishing vessels

Source	Vessel type	Year	Fuel consumption (million tonnes)	CO_2 emissions (Tg)	Fuel/CO_2 emissions ratio
Eyring (2005) (vessels >100 t only)	>100t (23 000 vessels)	2001	23.6[1]	69[1]	2.9
Tyedmers *et al.* (2005)	All vessels	2001	42	134	3.2
FAO (2007a)	1.3 million decked vessels	2005	14	43	3.05[2]

[1] Calculated by the proportion of large vessels which are fish factories or catching vessels.
[2] Average of the ratios used by Tyedmers and Eyering.
Source: FAO, 2007a.

TABLE 3
Fuel costs as a proportion of total revenue

	Gear category	Fuel cost as a proportion of total revenue in 2005 (percent)
Developing countries	Active demersal	52.3
	Active pelagic	33.4
	Passive gear	38.7
Developed countries	Active demersal	28.7
	Active pelagic	11.0
	Passive gear	9.2

Source: FAO, 2007a.
Note: fuel costs vary across countries.

BOX 2

Iceland: improving energy efficiency in the fisheries sector as a mitigation strategy

In countries and regions where fisheries are heavily industrialized and which are economically dependent on the fishing sector, emissions from fishing activity can be high. In Iceland, fishing and fish processing accounted for 40 percent of total exports in 2001 while the use of fossil fuels for fishing vessels explained about 26 percent of total GHG emissions. One of the Icelandic Government's objectives was to improve energy efficiency in the sector through education about energy saving options, equipping new vessels with the best available technology and the reduced use of HFC cooling systems.

Source: Iceland Ministry of Environment (2003) http://unfccc.int/resource/docs/natc/icenc3.pdf

sources and methodologies used. Eyring's estimate encompasses only the 23 000 largest vessels over 100 tonnes, whereas the world fleet contained 1.3 million decked vessels in 2004 (FAO, 2007a, p. 25). The methodology used by Tyedmers *et al.*, included all vessels and is thus, as would be expected, higher. FAO's estimate is considerably lower, perhaps reflecting reductions in the fishing fleet from 2001 to 2005. However, trends in vessel numbers would not explain the substantially lower estimate because reductions in some areas were compensated for by increases in others. For example, the number and total kW engine power of EU vessels declined by about nine percent (10 000 vessels and about 1 million kW), while, in spite of plans to address overcapacity, the size and power of China's fleet increased by seven and nine percent respectively (34 000 vessels and 1.3 million kW). Korean vessels declined slightly in number but their considerable engine power increased by about 2 million kW (14 percent, FAO 2007a, p. 27).

In some cases, mobile fishing gears, especially demersal trawls are less fuel efficient than static gears (Table 3). However, the energy efficiency of individual fishing operations needs to be specifically examined because some industrialized passive gear fisheries can be highly fuel intensive. Fuel costs in 2005 were estimated to be nearly

30 percent of revenue for mobile demersal gears in developed countries. Fleets in the developing world tend to be less fuel efficient in terms of costs and catch revenue, spending up to 50 percent of total catch revenue on fuel (Table 3). These figures do not allow absolute fuel consumption to be compared because they are affected by variable price of fuel and catch in different fisheries and countries.

Fuel efficiency can be reduced by poor fisheries management. The "race to fish" which can be exacerbated by certain management measures (e.g. total allowable catches without individual quotas) creates incentives to increase engine power. Meanwhile, overfished stocks at lower densities and lower individual sizes require vessels to exert more effort, catch a higher number of individual fish, travel to more distant or deeper fishing grounds and/or fish over a wider area to land the same volume of fish, all of which would increase fuel use per tonne of landings.

3.1.2 Mitigation of operational emissions

Increasing fuel costs are likely to continue to pressure the fishing industry to improve fuel efficiency in order to remain profitable. For example, switching to more efficient vessels or gears, such as from single to twin trawls (Tietze *et al.,* 2005). However, such practices are only estimated to offer a reduction in fuel use of up to 20 percent (FAO, 2007a). Options also exist for small-scale fishers to reduce their fuel use by improving the efficiency of their vessels, using sails or changing fishing behaviour (Wilson, 1999).

3.1.3 Emissions from trade

FAO estimates that 53 million tonnes of fish were internationally traded in 2004 (FAO, 2007a) including products of both fisheries and aquaculture. The transport of this fish will result in emissions of GHGs. High value fish products such as tuna imports to Japan, are frequently transported by air freight and thus would have especially large transport related emissions. Air freight imports of fish to the United States, Europe and Asia are estimated at 200 000, 100 000 and 135 000 tonnes, respectively (Conway, 2007). Fisheries may make a regionally significant contribution to air freight. For example fish, molluscs and crustaceans were the most frequently airfreighted commodity from New Zealand in 1997 (Statistics New Zealand, 2007), while 10 percent of all air freight from British Columbia in 1996 was fisheries products (British Columbia Stats, 1998).

Despite rapid increases in global air freight of fish products until the early 2000s, the quantities seem to have since stagnated. This may be because of competition with other airfreighted commodities, the reluctance of airlines to carry fish and a trend towards transport of fish frozen at source in refrigerated containers (Conway, 2007). Emissions per kilogram of product transported by air are many times higher than for those transported by sea. Saunders and Hayes (2007) estimate coefficients for the transport of agricultural products and the same coefficients should be relevant for fish export (though fish export may be higher if more refrigeration is used). Intercontinental air freight of fish may thus emit 8.5 kg of CO_2 per kilogram of fish shipped, which is about 3.5 times the emissions from sea freight and more than 90 times the emissions from local transportation of fish if they are consumed within 400 km of the source (Table 4).

Assuming that emissions per kilogram for fish were similar to intercontinental agricultural produce, the 435 000 tonnes of air freighted fish imports to the United States of America, Europe and Asia (Conway, 2007) would give rise to 3.7 Tg CO_2 emissions, which is approximately three to nine percent of the estimates for operational CO_2 emissions from fishing vessels. Emissions from the remaining, non-air freighted 52.5 million tonnes of internationally traded fish depend on the distance and transport mode used. From the figures in Table 5 for short-distance truck and non-bulk sea freight, this could range between 3 and 340 Tg CO_2 equivalent to between 2 and 780 percent of estimated operational fisheries emissions.

TABLE 4
CO_2 emissions associated with different transport modes for agricultural products

Transport mode and distance		gCO_2/kg
Short distance (<400km)		
	Truck	55
Intercontinental transport		
	Air freight	8 510
	Sea freight	
	Bulk	2 399
	Non bulk	6 424

Source: after Saunders and Hayes, 2007.

Clearly, more detailed information on transport modes is needed to provide a reliable estimate of emissions from fish transport, but it is possible that emissions from this sector are as significant as operational emissions. Continuing internationalization of the fish trade will increase fisheries' contributions to CO_2 emissions if transport efficiency and the ratio of air and surface freight remains the same, while increased use of bulk sea-freight or local consumption may reduce the overall emissions from fish transport.

3.1.4 Other potential contributions from fisheries to mitigation

Some initial research has been conducted into the utilization of waste products from fish processing for producing biodiesel. This may offer alternatives to fossil fuels or terrestrial biodiesels in specific instances where large quantities of fish fats are available. For example, a tilapia processing company in Honduras generates electricity and runs vehicles based on waste fish fat (Tony Piccolo, personal communication). This is based on the utilization of waste products from industrial processing of cultured fish. Given the nutritional value of fish, such uses are unlikely to be desirable in typical capture fisheries unless there are similarly large quantities of otherwise waste fish products.

3.2 Impacts of global mitigation actions on fisheries

Aviation and shipping currently lie outside any emissions trading scheme. Distant water fishing vessels that are supplied with fuel outside territorial waters are therefore not included and can also avoid domestic taxes on fuel. In contrast, vessels fishing within their own country's exclusive economic zone (EEZ) are liable to pay fuel duty and be incorporated into current mechanisms. As the post-Kyoto mechanism for 2012 is negotiated, aviation and shipping may become incorporated (EEA, 2008) with implications for the emissions and fuel use of all fishing vessels.

As the vast majority of fisheries operations are entirely reliant on fossil fuels, they are vulnerable to any decrease in the availability of, or increase in the price of fuel. The doubling of the diesel price during 2004 and 2005, for example, led to a doubling of the proportion of fishers' revenue that they spent on fuel and rendered many individual fishing operations unprofitable (FAO, 2007a).

With 40 percent of fish catch being internationally traded (Delgado *et al.,* 2003) increases in transport and shipping costs (i.e. through carbon taxes or other mitigation measures) will affect markets and potentially reduce the profitability of the sector. This may also affect the food security of poorer fish-importing countries as the costs of importing fish increase.

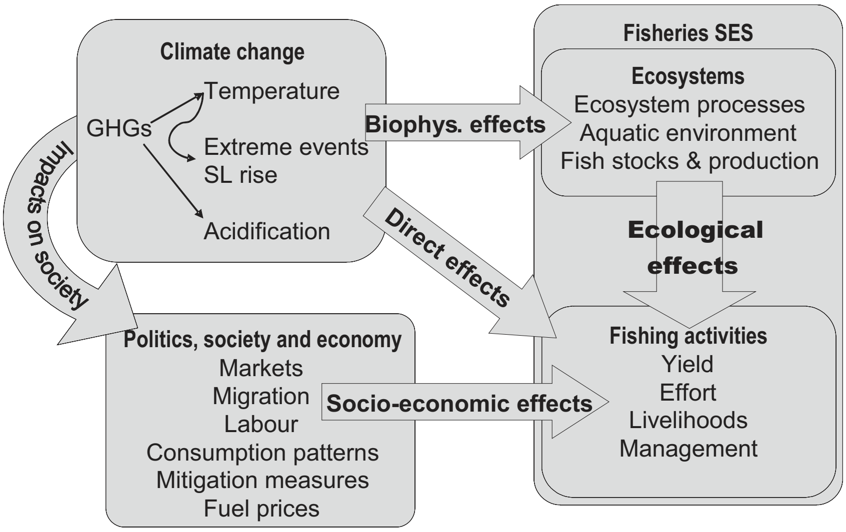
4. CLIMATE CHANGE IMPACTS ON FISHERIES

4.1 Potential impacts and impact pathways

Climate change can be expected to impact fisheries through a diverse range of pathways and drivers. Figure 3 illustrates that the effects of climate change can be direct or indirect, resulting from processes in aquatic ecological systems or by political, economic and social systems. This report focuses on the consequences of climate change at the point at which they impact on fishing activities, fishers and their communities.

FIGURE 3

Ecological, direct and socio-economic impacts of climate change on fisheries and some examples of each



Ecological impacts (covered in paper 1)	Direct impacts	Socio-economic impacts
Change in yield Change in species distribution Increased variability of catches Changes in seasonality of production	Damaged infrastructure Damaged gears Increased danger at sea Loss/gain of navigation routes Flooding of fishing communities	Influx of migrant fishers Increasing fuel costs Reduced health due to disease Relative profitability of other sectors Resources available for management Reduced security Funds for adaptation

A wide range of potential indirect ecological, direct and indirect socio-economic impacts on fisheries have been identified (Table 5, Allison *et al.*, 2005). In chapter one of this report, Barange and Perry summarize impacts in terms of biophysical effects on aquatic ecosystems. These have been the focus of most studies of climate change and fisheries, perhaps because of the prominence of natural science within climate and fisheries science and the complexity of indirect socio-economic impacts. Box 3 however, presents a case in which the biophysical and ecological impacts of climate change appear to have been be overwhelmed by socio-economic impacts even in remote, subsistence fishing communities.

4.2 Impacts by sector

4.2.2 Small-scale and artisanal marine fisheries

The small-scale sector is susceptible to a variety of indirect ecological impacts depending on the ecological system on which the fishery is based. Coral reefs, for example, support small-scale fisheries throughout the tropical western Atlantic, Indian and Pacific oceans and are at risk from elevated water temperatures and acidification in addition to a range of more direct local impacts (Hoegh-Guldberg *et al.*, 2007). The risk of severe bleaching and mortality of corals with rising sea surface temperatures may threaten the productivity of these fisheries. The distribution of coral reefs,

TABLE 5

Potential impacts of climate change on fisheries

Type of changes	Physical changes	Processes	Potential impacts on fisheries
Physical environment (indirect ecological)	Increased CO_2 and ocean acidification	Effects on calciferous animals e.g. molluscs, crustaceans, corals, echinoderms and some phytoplankton	*Potentially* ***reduced production*** *for calciferous marine resources and ecologically related species and* ***declines in yields***
	Warming upper layers of the ocean	Warm-water species replacing cold-water species	***Shifts in distribution*** *of plankton, invertebrates, fishes and birds towards the North or South poles, reduced species diversity in tropical waters*
		Plankton species moving to higher latitudes	
		Timing of phytoplankton blooms changing Changing zooplankton composition	*Potential mismatch between prey (plankton) and predator (fish populations) and* ***reduced production and biodiversity*** *and* ***increased variability in yield***
	Sea level rise	Loss of coastal fish breeding and nursery habitats e.g. mangroves, coral reefs	***Reduced production and yield*** *of coastal and related fisheries*
Fish stocks (indirect ecological)	Higher water temperatures	Changes in sex ratios Altered time of spawning Altered time of migrations Altered time of peak abundance	*Altered timing and* ***reduced productivity*** *across marine and fresh water systems*
	Changes in ocean currents	Increased invasive species, diseases and algal blooms	***Reduced productivity*** *of target species in marine and fresh water systems*
		Changes in fish recruitment success	*Abundance of juvenile fish affected leading to* ***reduced productivity*** *in marine and fresh water*
Ecosystems (indirect ecological)	Reduced water flows and increased droughts	Changes in lake water levels Changes in dry water flows in rivers	***Reduced productivity*** *of lake fisheries* ***Reduced productivity*** *of river fisheries*
	Increased frequency of ENSO events	Changes in timing and latitude of upwelling	***Changes in distribution*** *of pelagic fisheries*
		Coral bleaching and die-off	***Reduced productivity*** *coral-reef fisheries*
Disturbance of coastal infrastructure and fishing operations (direct)	Sea level rise	Coastal profile changes, loss of harbours, homes.	***Increased vulnerability*** *of coastal communities and infrastructure to storm surges and sea level*
		Increased exposure of coastal areas to storm damage	*Costs of adaptation lead to* ***reduced profitability****, risk of storm damage* ***increases costs*** *of insurance and/or rebuilding*
	Increased frequency of storms	More days at sea lost to bad weather, risks of accidents increased	***Increased risks*** *associated with fishing, making it less viable livelihood options for the poor*
		Aquaculture installations (coastal ponds, sea cages) more likely to be damaged or destroyed	***Reduced profitability*** *of larger-scale enterprises, insurance premiums rise*
Inland fishing operations and livelihoods (indirect socio-economic)	Changing levels of precipitation	Where rainfall decreases, reduced opportunities for farming, fishing and aquaculture as part of rural livelihood systems	***Reduced diversity of rural livelihoods;*** *greater risks in agriculture; greater reliance on non-farm income.* ***Displacement of populations*** *into coastal areas leading to influx of new fishers*
	More droughts or floods	Damage to productive assets (fish ponds, weirs, rice fields, etc.) and homes	***Increasing vulnerability*** *of riparian and floodplain households and communities*
	Less predictable rain/dry seasons	Decreased ability to plan livelihood activities – e.g. farming and fishing seasonality	

Source: adapted from Allison *et al.*, 2005.

BOX 3

Importance of socio-economic drivers in Fijian fishing communities

The Lau islands lie in a remote southeast province of Fiji and have limited land and transport networks. The islands are some of the most traditional in Fiji and the majority of households participate in subsistence fisheries.

Following a temperature-induced mass coral mortality event in 2000, and damage to corals from crown of thorns starfish outbreaks in 1999, it might be expected that fisheries and local communities who used those reefs would be directly impacted. However, a socio-economic survey conducted in the area in 2006 found that, while some fishers were aware of the bleaching and starfish phenomena, few identified them as a threat to fish populations. Most fishers had not perceived a decline in fisheries and none had adjusted their fishing practises as a result. Despite the remoteness of these communities and the presence of subsistence fishing, the major change in livelihoods on the islands appeared to have been driven by an export market opportunity (carving ceremonial wooden bowls) rather than the ecological impacts from the climate-mediated bleaching and starfish outbreak.

This case is based on a relatively small survey of a particular island group and so should not be generalized, but it illustrates how assumptions about the prominence of biophysical and ecological drivers in subsistence fisheries can be misleading.

Source: Turner *et al.*, 2007.

coinciding with large numbers of developing country populations in Southeast Asia, East Africa and throughout the Pacific, suggest that many millions of small-scale fishers are dependent on coral reefs for their livelihoods (Whittingham, Campbell and Townsley, 2003a). Nearshore habitats and wetlands, like mangroves and seagrass beds which are often the target areas of small-scale fishers, or which may provide breeding or nursery areas for important species, may be impacted by sea level rise, especially where coastal development restricts landward expansion of the ecosystem (Nichols *et al.*, 2007a).

As species distributions change in response to climate change, small-scale fishers may be less able to adapt by following them because of limited mobility. Traditional area-based access rights institutions will become strained by the loss or relocation of local resources. However, while some fisher folk will see the disappearance of their target species, others could see an increase in landings of species of high commercial value. For example, in the Humboldt Current system during El Niño years, landings of shrimp and octopus increase in northern Peru while in the south, tropical warm-water conditions increase the landings of scallops. These species have higher market values than more traditional species and international markets have developed for them (Badjeck, 2008).

Additionally, input of fresh water in estuaries may favour the appearance of brackish water species. For example, during the El Niño of 1997 to 1998, increased rainfall in northern Peru changed salinity patterns in estuaries, favouring the mullet fishery (Badjeck, 2008) and in Columbia during the La Niña event of 1999 to 2000, a tilapia fishery boom was observed in Columbia. This was caused by salinity changes (Blanco, Narváez Barandica and Villoria, 2007).

Small-scale fishers are particularly exposed to direct climate change impacts because they tend to live in the most seaward communities and are thus at risk from damage to property and infrastructure from multiple direct impacts such as sea level rise, increasing storm intensity and frequency. Worsening storms also increase the risks associated with working at sea, and changes in weather patterns may disrupt fishing practises that are based on traditional knowledge of local weather and current systems.

Disruption of other sectors (e.g. agriculture, tourism, manufacturing) by extreme events could lead to indirect socio-economic effects. The displacement of labour into fishing can lead to conflicts over labour opportunities and increased fishing pressure. This was observed as a result of hurricanes in the Caribbean (Mahon, 2002). Droughts and resultant agricultural failure forecast in some areas of sub-Saharan Africa (Conway *et al.*, 2005) may lead to so-called "environmental refugees" moving to coastal areas and creating an influx of surplus fishing labour.

The livelihoods of small-scale fishers are already vulnerable to a range of non-climate risks, including fluctuating resources, loss of access, HIV/AIDS, market fluctuations, conflict, political marginalization and poor governance (Allison, Beveridge and van Brakel, 2008). This insecurity inhibits investment in long-term strategies for sustainable fisheries and will be exacerbated by additional insecurities caused by climate change impacts. Small-scale fishers also generally lack insurance.

4.2.3 Large-scale marine fisheries

Many of the world's largest fisheries (most notably the Peruvian anchoveta – responsible for more than 10 percent of the world's landings) are based on upwelling ecosystems and thus are highly vulnerable to changes in climate and currents. Annual catches of Peruvian anchoveta, for example, have fluctuated between 1.7 and 11.3 million tonnes within the past decade in response to El Niño climate disruptions.

Large-scale changes affect the distributions of species and, hence, production systems. For example, the predicted northern movement of Pacific tuna stocks (Miller, 2007) may disrupt fish-based industries because existing infrastructure (e.g. landing facilities and processing plants) will no longer be conveniently located close to new fishing grounds. In addition, changes in the distribution of stocks and catches may occur across national boundaries.

A lack of well-defined and stable resource boundaries present particular challenges for fisheries governance in the context of climate change. Changes in fish stock distribution and fluctuations in the abundance of conventionally fished and "new" species may disrupt existing allocation arrangements. For instance, changes in Pacific salmon distribution as a result of sea surface temperatures and circulation patterns have led to conflicts over management agreements between the United States and Canada (Pacific Salmon Treaty, Miller, 2000). Similarly, it is forecast that temperature changes in the Pacific Islands could lead to a spatial redistribution of tuna resources to higher latitudes within the Pacific Ocean, leading to conflicts over the stock of tuna between industrial foreign fleets and national ones restricted to their EEZ (World Bank, 2000). Such problems can also occur on subnational scales between local jurisdictions, traditionally managed areas or territorial rights systems.

Rigid spatial management tools, such as permanently closed areas to protect spawning or migration areas, management schemes based on EEZ boundaries or transboundary fisheries management agreements may become inappropriate for new spatial fish stock configurations. Temporal management instruments (e.g. closed seasons) may also become ineffective if the seasonality of target species changes in response to altered climate regimes.

Industrial fisheries are also prone to the direct climate change impacts of sea level rise and increasing frequency and intensity of extreme weather. As with small-scale fisheries, fishing operations may be directly disrupted by poor weather, while extreme events can damage vessels and shore-based infrastructure. City ports and facilities required by larger vessels may be affected. An increasing number of large coastal cities are at risk from sea level rise and extreme weather, especially in rapidly developing Asian economies (Nicholls *et al.,* 2007a).

Indirect socio-economic impacts on industrial fisheries may include flooding or health impacts on vulnerable societies which may affect employment, markets or processing facilities. The aquaculture industry is a major market for fishmeal from capture fisheries and climate change impacts may affect markets for reduction fisheries, although current projections are for fishmeal and fish oil demands to continue to increase in the near future (Delgado *et al.*, 2003).

Positive indirect impacts for some fisheries may result from declines in other fisheries which compete for global markets. For example, while eastern pacific upwelling fisheries were adversely affected in El Niño years, Danish fishers received near record prices for Baltic sprat, a competing species for fishmeal production (MacKenzie and Visser, 2001).

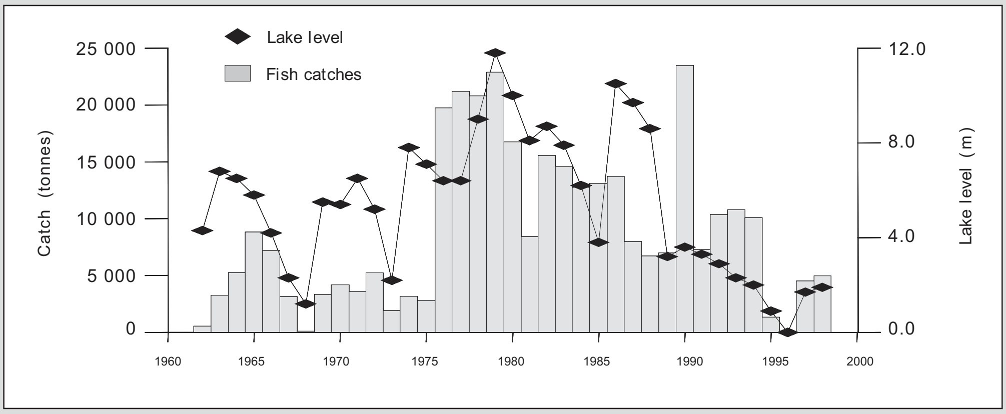
4.2.4 Inland fisheries

Inland fisheries ecology is profoundly affected by changes in precipitation and run-off which may occur due to climate change. Lake fisheries in southern Africa for example, will likely be heavily impacted by reduced lake levels and catches (Box 4).

In basins where run-off and discharge rates are expected to increase, the seasonal inundation of river floodplains such as those in the Ganges Basin in South Asia, fish yields may increase as larger areas of ephemeral spawning and feeding areas are exploited by lateral migrant species. In Bangladesh, a 20 to 40 percent increase in flooded areas could raise total annual yields by 60 000 to 130 000 tonnes (Allison *et al.*, 2005). However, whilst the discharge rates and flooded areas of many rivers in South and South-East Asia may increase, their dry season flows are often predicted to decline and exploitable biomass is more sensitive to dry, than flood season conditions (Halls, Kirkwood and Payne, 2001). Any increases in yield arising from more extensive flooding may therefore be offset by dry season declines. In addition, changes to the hydrological regime and the risk of droughts and flooding may create further incentives to invest in large-scale infrastructure projects like flood defences, hydropower dams and irrigation schemes, which are already known to have complex (and often negative) interactions with fisheries (e.g. Shankar, Halls and Barr, 2004).

BOX 4

Precipitation and inland African fisheries



The shallow, highly productive Lake Chilwa in Malawi supports a US$10 million a year fish trade. However, rainfall variations have led to periodic drying out of the entire lake and time-series demonstrate that the productivity of the fishery is strongly tied to the amount of water in the lake. During drought periods, some fishers diversified their livelihoods to farming, pastoralism and other occupations, while some wealthier, more specialized fishers, migrated to fisheries in other lakes in the region.

Source: after Allison *et al.*, 2007.

4.3 Market and trade impacts

Fisheries can be affected by direct climate impacts on processing and trade. For example, following hurricane Katrina, fishers in the Mississippi area of the United States were unable to sell, catch or buy fuel or ice (Buck, 2005) while heavy rain in Peru in 1998 disrupted road networks and prevented rural fishing communities from accessing their usual markets (Broad, Pfaff and Glantz, 1999).

Increasing frequency of algal blooms, shellfish poisoning and ciguatera poisoning because of warming seas, ecological shifts and the occurrence of water-borne human pathogens, like *Vibrio* in areas affected by flooding may lead to fears over fish contamination. These factors may adversely affect fish markets (Patz, 2000; Hales, Weinstein and Woodward, 1999) although this impact is still uncertain.

4.4 Potential positive impacts

In addition to negative impacts, climate change is likely to create opportunities and positive impacts in some fisheries, although these are not well understood or described in the literature. In chapter one of this report, Barange and Perry highlight several mechanisms in which fisheries production may increase or entirely new fisheries evolve. In inland waters, fisheries created by increases in flooded areas may partially offset the loss of land for agriculture or other economic activities. In Peru, increased sea surface temperatures negatively affect pelagic fisheries for small-scale artisanal fishers, but also bring a variety of (sub) tropical immigrants and expands the distribution zone of some species, illustrating very well how climate change could bring new opportunities to fisher folk and their communities. Indeed, during the El Niño of 1982 to 1983 and 1997 to 1998, penaeid shrimps and rock lobsters from the Panamic Province appeared in Peru (Arntz, 1986; Arntz *et al.*, 2006). These species, along with dolphin fish (*mahi-mahi*), tuna and diamond shark created a new economic opportunity for the artisanal fishing sector (CAF, 2000).

An extreme case is the potential creation of an entirely novel open water fishery as a result of the melting of the Arctic Ocean. The management of as yet nonexistent fisheries with no prior governance arrangements provides a challenge in terms of uncertainty and lack of experience, but also an opportunity to develop governance and management with precautionary limits before overcapacity develops. The adaptive capacity of economies, fishing sectors, communities, individuals and governance systems will determine the extent to which they are able to maximize the opportunities created by new fisheries.

4.5 Observed and future impacts

4.5.1 Observed impacts of climate change and variability

Many fisheries are known to be profoundly controlled by climate variability through ecological impacts (e.g. Box 5). Meanwhile, long-term climate-related changes have been observed in marine ecosystems (IPCC, 2007) including in targeted fish populations. However, in spite of the ecological changes that have been recorded, impacts on fisheries have largely yet to be discerned from pre-existing variability and non-climate impacts (of overexploitation, market fluctuations etc.). Even fisheries associated with coral reefs that have been profoundly impacted by climate change have yet to demonstrate a significant impact (see Box 6). Although a lowering of ocean pH of 0.1 unit has been observed since 1750, no significant impacts of acidification on fisheries have yet been observed (Nicholls *et al*., 2007b) although long-term forecasts are alarming (Orr *et al.,* 2005).

Coastal zones throughout the world are experiencing erosion (Nicholls *et al*., 2007b), threatening coastal communities with flooding and loss of coastal ecosystems. A variety of processes are responsible for this, including changes in land use. However, erosion may also be exacerbated by climate-mediated sea level rise, although the

BOX 5

The impacts of climate variability on Peruvian Anchoveta fisheries

More than 95 percent of Peruvian fisheries catches, which are dominated by pelagic resources such as anchovies (*Engraulis ringens*), are landed by the industrial sector (Majluf, Barandearán and Sueiro, 2005). Additionally, the sector is the second highest generator of foreign currency after mining, accounting for US$1 124 million in exports in 2001 (FAO, 2003b). However, the harvest of anchovies is extremely variable because of population fluctuations induced by warm modes of the El Niño-Southern Oscillation (ENSO), commonly known as El Niño. El Niño events reduce upwelling along the Peruvian coast, thereby impacting on the natural process that provides nutrients for the anchovies and causing a significant decrease in anchovy biomass. During the 1998 El Niño the anchovy biomass was estimated at 1.2 million tonnes, the lowest in the 1990s (Ñiquen and Bouchon, 2004). During the 1997 to 1998 El Niño, total volumes of fisheries landings decreased by 55 percent compared to 1996 (CAF, 2000). It is estimated that the direct cost to the fisheries sector was 73.7 million Peruvian soles (PEN) or US$26.3 million (1998 exchange rate), with a negative effect on the country's balance of payments of around PEN8.4 million (CAF, 2000). Because Peru is the main producer of fishmeal and fish oil in the world, fluctuations of anchovy stocks not only have an impact at national level but also on the global aquaculture feed market.

While the industrial fishery sector was adversely affected by the reduced stock of anchovies and sardines in the eastern Pacific upwelling areas, fisher folk in Denmark received near record prices for Baltic sprat, a competing species for fishmeal production (MacKenzie and Visser, 2001). And climate variability in Peru is not always synonymous with negative effects for the fishmeal industry; La Niña events (cooling of sea surface temperatures) have led to increased catches of anchovies and revenues for the industrial sector (Ordinola, 2002).

BOX 6

Coral bleaching impacts on fisheries in the western Indian Ocean

Coral bleaching is a biological phenomenon in which stony corals and related organisms, lose the symbiotic algae normally found in their tissues as a result of stress (including unusually high water temperatures). As a result, the corals appear white; they may recover but can die if bleaching is severe or prolonged. Coral reefs in the western Indian Ocean region experienced very severe bleaching and mortality because of the El Niño of 1998 to 1999 and were bleached again in 2005. Inner reefs of the Seychelles showed severe ecological consequences. Live coral cover dropped from 27 percent to three percent, and coral-feeding fish species disappeared (Graham *et al.*, 2006). However, fisheries landing statistics and surveys of the biomass of targeted species have yet to demonstrate the impact of the bleaching (Grandcourt and Cesar 2003; Graham *et al.*, 2007). This may be because fish habitats were still provided by the structure of the dead corals. These have subsequently begun to erode, leading to a loss of structure. Ecological studies undertaken in 2005 found a reduced abundance of small fish. This may indicate a time lag in the impacts of bleaching on commercially important fish, with the erosion of dead corals eventually affecting recruitment of commercially important fish species (Graham *et al.*, 2007).

complexity of coastal dynamics makes it difficult to isolate the impact of climate change (Nicholls *et al.*, 2007b).

4.5.2 Likely additional impacts within the next 50 years

Existing climate trends will increase over the next century (IPCC, 2007) and are expected to impact more severely on aquatic ecosystems and, directly and indirectly, on fishing sectors, markets and communities. Loss of corals through bleaching is very likely to occur over the next 50 years, with consequent impacts on the productivity of reef fisheries and potentially on coastal protection as reefs degrade. Sea level will continue to rise and by 2100 will have increased by a further 20 to 60 cm, leading to elevated extreme high sea levels, greater flooding risk and increased loss of coastal habitats.

In addition to incremental changes of existing trends, complex social and ecological systems such as coastal zones and fisheries, may exhibit sudden qualitative shifts in behaviour when forcing variables past certain thresholds (Scheffer *et al.,* 2001; Lenton *et al*., 2008). In addition to this non-linearity in systems, assumptions of gradual change may be based on an incomplete understanding of the mechanisms which will lead to more rapid shifts. For example, IPCC originally estimated that the Greenland ice sheet would take more than 1 000 years to melt, but recent observations suggest that the process is already happening faster owing to mechanisms for ice collapse that were not incorporated into the projections (Lenton *et al*., 2008). Similarly, predictions of changes to fisheries' social and ecological systems may be based on inadequate knowledge of mechanisms and potential "tipping elements", which might be responsible for sudden or irreversible changes. Climate change may, therefore, result in sudden, surprising and irreversible changes in coastal systems (Nicholls, 2007). The infamous collapse of the Northwest Atlantic northern cod fishery provides a (non-climate-related) example where chronic overfishing led to a sudden, unexpected and irreversible loss in production from this fishery. Thus, existing observations of linear trends cannot be used to reliably predict impacts within the next 50 years.

4.5.3 Impacts of climate change in the context of other trends

Future impacts of climate change on fisheries need to be seen in light of the considerable changes which might be expected within society regardless of climate change, for example in markets, technology and governance (Garcia and Grainger, 2005). This evolving context for fisheries may mean that the impacts of climate change cannot be predicted by analysing how fisheries systems in their contemporary state will be affected by future climate change. It is likely that in the future, climate change will impact on future fisheries in different configurations from the current situation. For example, if fisheries are better managed in the future through incentive-based and participatory management of the ecosystem and with more efficient enforcement (Hilborn *et al*., 2003), then fish stocks will be better able to withstand biophysical impacts on recruitment and fisheries ecosystems will be more resilient to changes. In a world in which demand for fish increases, prices continue to rise and fisheries become increasingly globalized (Delgado *et al.,* 2003), commercial fisheries may be able to maintain profitability in the light of declining yields. However, subsistence fisheries and local markets in poorer countries may become more sensitive to economic demand from richer countries and as more fish production is directed to exports, the contribution of fisheries to food security may decline in poorer countries.

4.5.4 Synergistic impacts

Literature on climate change impacts (including this report) necessarily tend to list separate impacts but it is important to be aware of potential synergistic and cumulative effects of multiple impacts (see Box 7, for example).

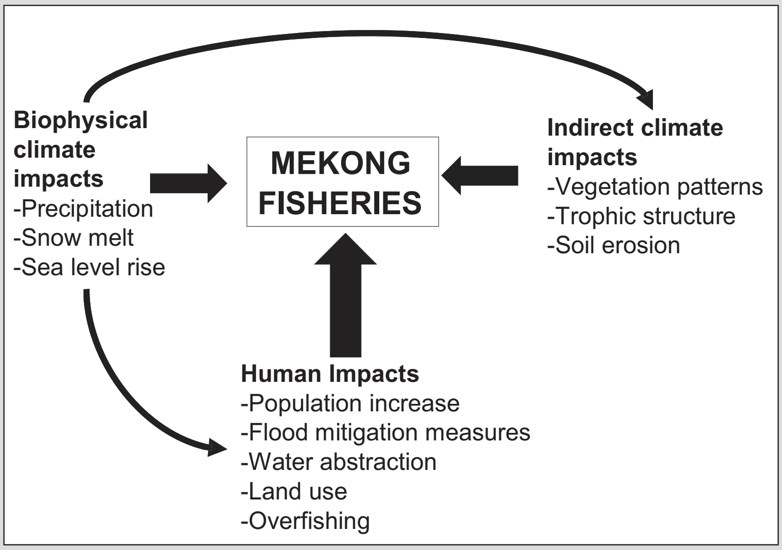
4.5.5 Uncertainty of impacts

While successive IPCC reports have documented an increasing scientific certainty that climate change is occurring and an increasing range of observed impacts, there is still

BOX 7

Multiple impacts on Mekong Delta fisheries

The lower Mekong Delta supports more than 1 000 fish species, a capture fishery of 1.5 million tonnes and fishery based livelihoods for 40 million people. These fisheries are threatened by a number of climate mediated processes, including changing precipitation, snow melt and rising sea level, which have impacts on various aspects of the delta's ecology and on human settlements.



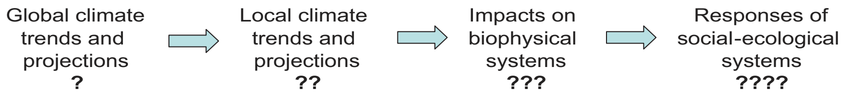
In addition to these interacting climate impacts, the overwhelming impacts on fisheries in the delta are from human activities including overfishing, land use changes and hydrological disruptions. Increased flooding in future has the potential to increase fishery yields, but planned flood mitigation measures to protect agriculture may result in reduced flooding and reduced fisheries productivity.

Source: Easterling *et al.*, 2007.

considerable uncertainty in the extent, magnitude, rate and direction of changes and impacts. Meanwhile, unlike for terrestrial systems supporting agriculture, there is a lack of quantitative predictions of climate effects on aquatic systems (Easterling *et al.*, 2007). The relative importance of different impacts and potential interactions between them are very poorly understood and the uncertainty in predictions about climate variables is amplified by poorly understood responses of biophysical systems. A further complexity and unpredictability is in how people and economies, and *their* complex relationships with local ecosystems might respond to change (Allison, Beveridge and van Brakel, 2008, Figure 4). This underscores the need for social scientists as well as economists and natural scientists to be engaged in policy recommendations and management. It also emphasises the need for fisheries governance regimes to be flexible

FIGURE 4

Increasing uncertainty along the pathway of impacts of climate change



enough to adapt to and learn from unforeseen changes (i.e. to have high adaptive capacity). Frameworks such as adaptive co-management (Armitage *et al.*, 2008) are being developed and may provide some of this flexibility but as yet they have not been fully tested on a larger scale.

4.6 Vulnerability of regions, groups and hot spots

Climate change impacts on fisheries will have uneven effects on different geographic areas, countries, social groupings and individuals. Vulnerability depends not only on the distribution of climate impacts (exposure) but on their sensitivity and adaptive capacity. Thus vulnerability is socially differentiated: virtually all weather-related hazards associated with climate variability, as well as human causes of vulnerability, impact differently on different groups in society. Many comparative studies have noted that the poor and marginalized have historically been most at risk from natural hazards and that this vulnerability will be amplified by climatic changes (IPCC, 2007). Poorer households are, for example, forced to live in higher risk areas, exposing them to the impacts of coastal flooding and have less capacity to cope with reduced yields in subsistence fisheries. Women are differentially at risk from many elements of weather-related hazards, including, for example, the burden of work in recovery of home and livelihood after a catastrophic event (Adger *et al.*, 2007).

Assessing the vulnerability of different geographic areas, countries, social groupings and individuals, aims to identify those who will be most adversely affected, which information can be used to guide policy and interventions to assist adaptation.

4.6.1 Geographic regions with high potential exposure

The greatest warming of air temperatures thus far has been experienced in high latitudes and this is likely to continue with future climate change. However, changes in water temperatures are less well predicted and are mediated by ocean currents. Only some climate impacts on fisheries are mediated by temperature (Figure 3), so projected air temperature changes commonly presented in climate forecasts are a poor measure of potential exposure. Low latitude regions, for example, where fisheries rely on upwellings, coral reef systems or susceptible fresh water flows may be more exposed to climate impacts than high latitude regions where most warming is predicted.

IPCC (2007) predictions suggest that tropical storm intensity will increase, specifically impacting fishing communities and infrastructure in tropical storm areas (Figure 5). It is also possible, but less certain, that the existing tropical storm belt will expand to affect more areas. In this case, communities for whom tropical storms are a novel disturbance may initially be more sensitive if they lack appropriate infrastructure design, early warning systems and knowledge based on previous experience.

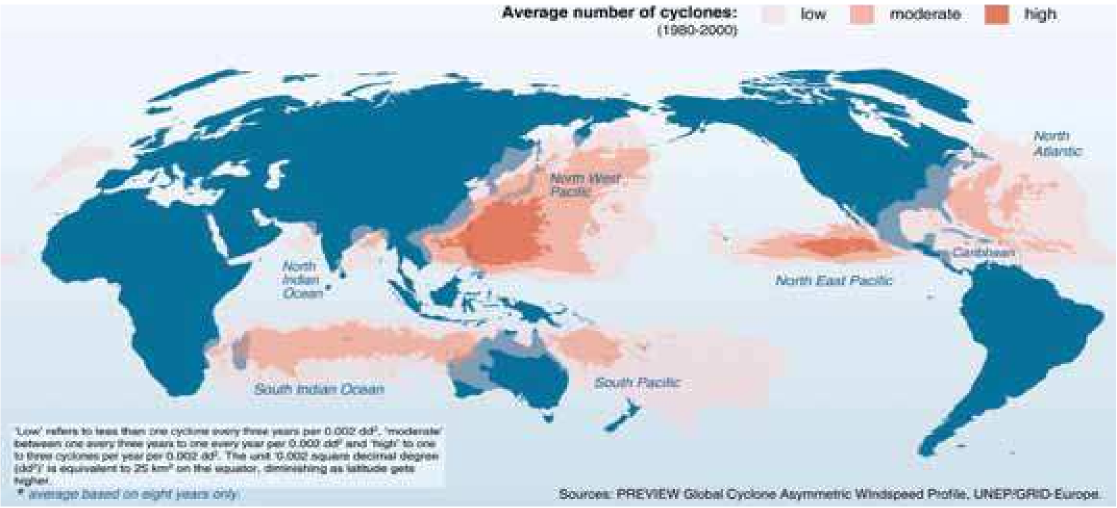
Fisheries communities located in deltas or on coral atolls and ice dominated coasts will be particularly vulnerable to sea level rise and associated risks of flooding, saline intrusion and coastal erosion (Nicholls *et al.*, 2007a).

4.6.2 Vulnerable economies

Developing countries in tropical regions are usually assumed to have lower adaptive capacities than countries with high levels of economic and human development. This is because of lower availability of resources and institutions necessary to facilitate adaptation.

A national level analysis of the vulnerability of 132 economies to climate impacts on fisheries used predicted climate change, the sensitivity of each economy to disruption to fisheries and adaptive capacity, as indicated by statistics on development and GDP (Allison *et al.*, 2005). According to the resultant index, countries in western and central Africa (because of low levels of development and high consumption of fish), northwest South America (due to very large landings) and four Asian countries were most

FIGURE 5
Tropical cyclone frequency



Source: www.unep.org/newscentre/graphics/deadwater.

vulnerable (Figure 6).[2] Russia and Ukraine were the only two high latitude countries identified with high vulnerability due to the high degree of expected warming and low adaptive capacity scores.

The analysis highlighted the importance of low adaptive capacity for elevating the vulnerability of African countries even though greater warming is predicted at higher latitudes. While the analysis was a pioneering study of vulnerability of fisheries to climate change, there are several limitations. Firstly, projected increase in air temperature was assumed to be an indicator of exposure to climate change, whereas extreme events or non temperature mediated impacts may be most important. Secondly, data availability prevented the inclusion of most small island developing states, expected to be vulnerable because of a high reliance on fisheries, low adaptive capacity and high exposure to extreme events. Finally, analysis at the national scale required crude generalizations about countries which may miss sub national hotspots of vulnerable sectors or communities.

To improve large-scale mapping of vulnerability, more detailed predictions of changes in the likelihood of extreme events, hydrology and oceanography are needed to better characterise exposure. Integrative earth science and ecology projects such as the United Kingdom Natural Environmental Research Council (NERC)'s Quest-Fish project will make some advances to better characterizing aspects of exposure to move beyond use of projected air temperature changes (web.pml.ac.uk/quest-fish). Meanwhile, higher resolution, sub national data on resource use, fish consumption and trade, fisheries production and poverty will allow more detailed mapping of sensitivity and adaptive capacity.

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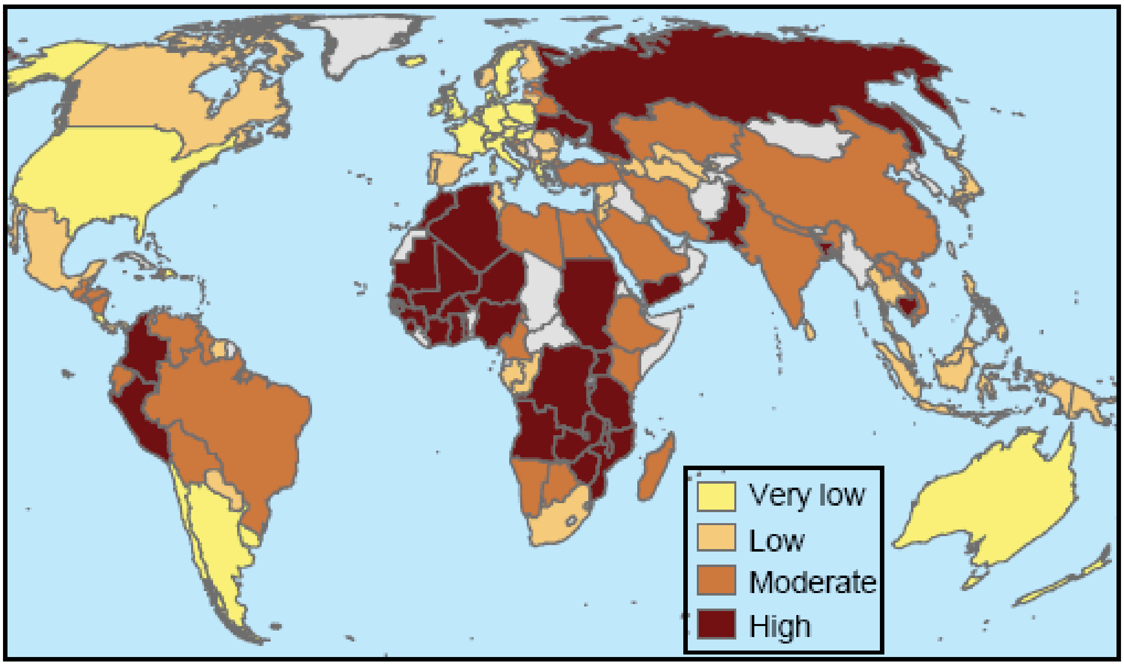
[2] From Allison *et al.* (2005): "Vulnerability was assessed as a function of risk exposure, sensitivity and adaptive capacity. Risk exposure was assessed in terms of projected mean temperature change; sensitivity was based on the relative importance of fisheries in terms of production, employment, export revenues and proportional contribution to GNP and agricultural GNP, as well as contribution to dietary protein. Adaptive capacity was assumed to be related to human development indices (HDIs) and economic performance data – countries with higher HDIs and higher per capita gross domestic product (GDP) are assumed to have higher adaptive capacity. Because poverty data are not widely available for fisher folk, it was necessary to use national level averages and assume the distribution of poverty was similar to the average national distribution".

FIGURE 6
Comparative vulnerability of national economies to climate impacts on fisheries



Source: Allison *et al.*, 2005.

4.6.3 Vulnerability of communities

Vulnerability can also be analysed based on statistics at the sub national level. For example, McClanahan *et al.* (2008) derived an index of adaptive capacity with respect to a loss of fishing livelihoods of 29 coastal communities in five nations in the western Indian Ocean (Kenya, Madagascar, Mauritius, Seychelles and Tanzania). The index combined eight variables proposed to be important for adaptive capacity weighted according to relative importance as judged by experts from across the region. The resultant ranking of communities (Figure 7) could broadly have been predicted from national level development statistics but exceptions include communities in Madagascar (with the lowest development status of the five nations), which score more highly than communities in richer countries because of high occupational mobility, "decline response" and "social capital" (e.g. Sahasoa). Thus a range of factors indicate adaptive capacity, and wealth may not be a complete indicator.

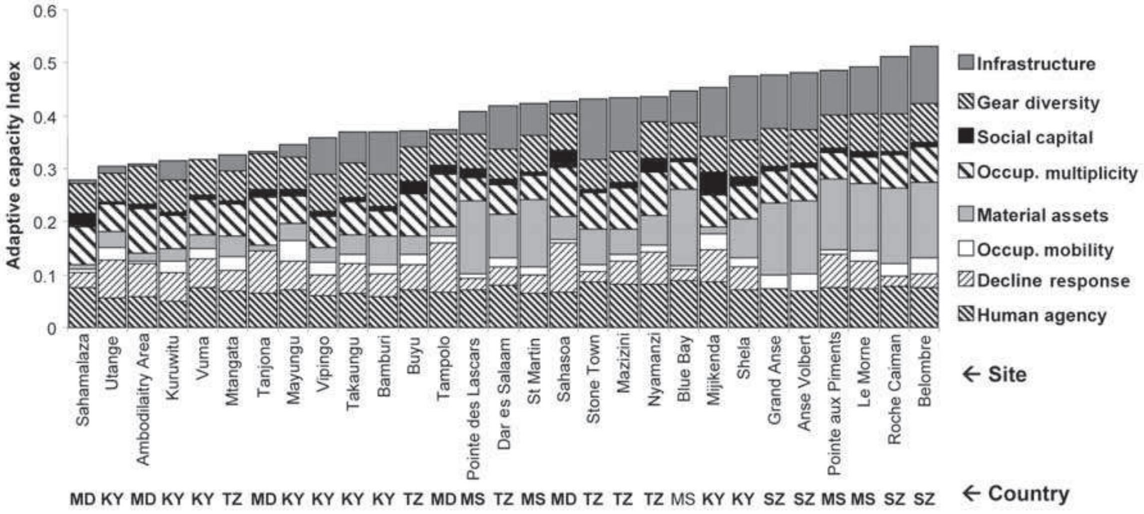
4.6.4 Vulnerable groups within society (demographic variations in vulnerability)

At even finer scales, vulnerability varies between individuals within a community, with some groups particularly vulnerable. Figure 8 is derived from the same data as Figure 7 but shows the range of household adaptive capacity within each community and country. There is as much variation in adaptive capacity between individual households as between communities or between countries, exemplifying the way in which adaptive capacity varies at national, community and individual household level.

Vulnerability is often assumed to be generally correlated with poverty. Hurricane Katrina, which hit New Orleans in August 2005, demonstrated how the poor are particularly vulnerable, even in the most prosperous countries. Poor families, including a high proportion of African Americans, were less likely to evacuate in advance of the hurricane leading to higher death tolls and subsequent impacts on housing, education and psychological state (Save the Children, 2007). Poorer members of communities are also least likely to have insurance or access to early warning information.

FIGURE 7

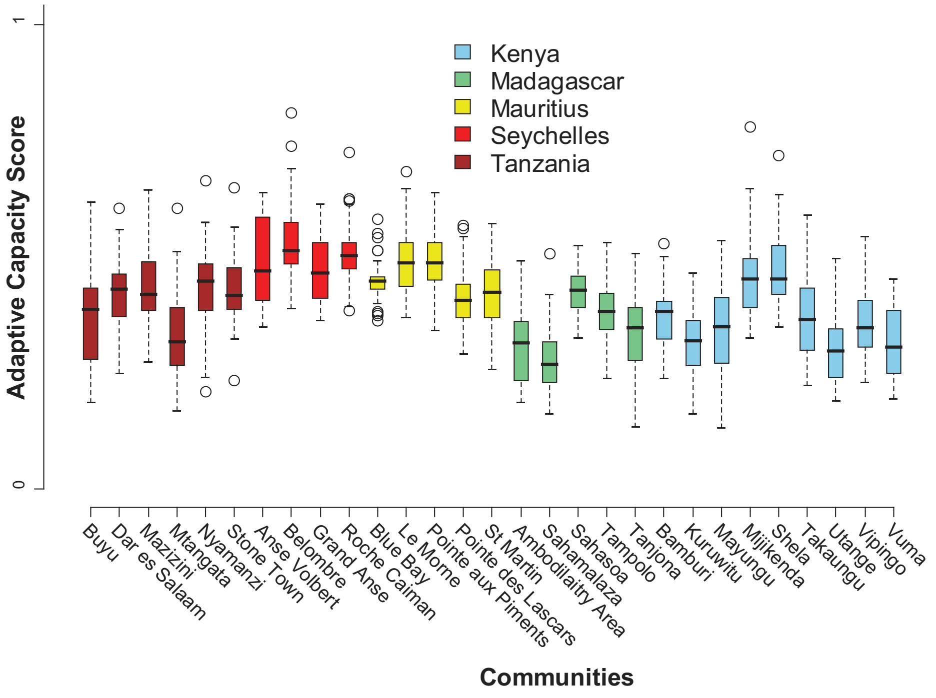
Assessment of the adaptive capacity of 29 East African communities



Source: McClanahan *et al.,* 2008.
Notes: MD - Madagascar, KY - Kenya, TZ - Tanzania, MS - Mauritius, SZ – Seychelles.
Adaptive capacity is measured as a compound of seven household and one community level (infrastructure) variables.
"Decline Response" is an index reflecting the proportion of fishers who would envisage exit from a declining fishery.

FIGURE 8

Range of adaptive capacity index for individual households within communities in five countries in the western Indian Ocean



Source: McClanahan *et al.* (unpublished data).

In addition to vulnerability to disasters, the poorest members of society are generally assumed to have less adaptive capacity to cope with gradual changes or declines in livelihoods. For example, in a fisheries context, Kenyan fishers from poorer households were more likely to be trapped in a declining fishery (Box 8).

Individual factors other than poverty can also affect vulnerability. For example, women are more vulnerable to natural hazards and climate change impacts owing to

BOX 8

Adaptive capacity of Kenyan fishers related to household socio-economics

A study of Kenyan fishers' readiness to exit from fishing in the face of declining catches found significant relationship between those who said they would stop fishing in response to a 50 percent decline in catches and socio-economic variables at the household level. Fishers from wealthier households (as judged by material style of life, house materials and ownership of appliances) were more likely to say they would exit the fishery. Livelihood opportunities at the household level were also significant; the probability of exit was significantly related to the total number of occupations in the household.

Statistical relationship between wealth, household occupations and probability of fishers saying they would exit in response to a 50 percent catch decline. The points show the actual data; lines show the relationships from a binomial logistic regression.

Source: Cinner *et al.* (2009).

increased likelihood of being around the home and increased burdens of care after hazards. It is also assumed for many societies that women possess lower levels of adaptive capacity to men. For example, they have fewer economic options, generally lower education attainment, a greater lack of rights and access to resources and may be more likely to endure the burden of care after hazards. Women headed households, which tend to be among the poorest households in many societies are considered especially vulnerable. The importance of contextual factors is well illustrated by studies of the impacts of the 2004 Indian Ocean Tsunami (Oxfam International, 2005). Throughout the affected coastal region, many more women than men were killed; in some communities two to three times more women than men. A range of factors made women more vulnerable and some were very locale and context specific. For example, they included ability to swim, physical strength and the need to protect and care for children and elderly. At some locations, because of women's roles in processing and marketing fish, women were waiting on the shore for fishing boats to return at the time of day the tsunami struck. Because of this they suffered higher levels of mortality than the men at sea. Of course these differential deaths have significant implications for relief and rehabilitation and long-term impacts on families and communities. However, there are relatively few rigorous empirical studies (see Vincent, 2006), so the literature abounds with generalizations and unproven assumptions. In many situations, for example, women may have access to abundant and diverse forms of social capital which may provide excellent support to overcome certain types of impacts or extreme events.

4.6.5 Gaps in knowledge about vulnerability

The ability to identify those most vulnerable to climate change is limited by the lack of high resolution data at appropriate scales and by uncertainty as to the processes that make people and places vulnerable. The IPCC Fourth Assessment highlighted that, in terms of impacts and adaptation, knowledge, monitoring and modelling of observed and future impacts is skewed towards developed nations (IPCC, 2007).

Changing resource scarcity or unpredictability as a result of climate change will clearly affect those whose entire livelihoods are directly dependent on fisheries. But it is unclear whether such dependence on fisheries will underpin efforts to attain sustainable management (as observed in some circumstances and explained by commons management theory); will result in greater overexploitation as future availability becomes uncertain; or will lead to an emphasis on diversification out of fisheries based livelihoods altogether, which may have significant social and even environmental impacts. All three generic responses are likely to occur. Hence defining the goals of desirable and sustainable adaptation for different stakeholders is an important research task for regions at risk.

There is a lack of understanding of how adaptation strategies in general, in coastal areas affected by multiple impacts of climate change, may impact other strategies and neighbouring coastal areas. For example, it has been shown that flood mitigation measures in Bangladesh to protect farmland may negatively affect fisheries (e.g. Shankar, Halls and Barr, 2004). Similarly, hard engineering coastal protection can impact on sediment loading and coastal dynamics in neighbouring coastal areas or countries. And increased “roving” of commercial fishing fleets as stocks migrate will have impacts on neighbouring or even distant countries.

Finally, there may be major thresholds in ecological and physical systems in oceans and coastal areas that directly affect vulnerability of these regions. These include stock collapse thresholds, ocean acidification and its impact of calcifying organisms and rises in temperature above a threshold for mass coral bleaching. The risk of such major shifts in ecology increases the exposure and vulnerability of dependent communities, but may not be known until after a threshold is passed.

5. ADAPTATION OF FISHERIES TO CLIMATE CHANGE

Adaptation to climate change is defined in the climate change literature as an adjustment in ecological, social or economic systems, in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change, or take advantage of new opportunities. In other words, adaptation is an active set of strategies and actions taken by people in reaction to, or in anticipation of, change in order to enhance or maintain their well-being. Adaptation can therefore involve both building adaptive capacity to increase the ability of individuals, groups or organizations to predict and adapt to changes, as well as implementing adaptation decisions, i.e. transforming that capacity into action. Both dimensions of adaptation can be implemented in preparation for, or in response to impacts generated by a changing climate. Hence adaptation is a continuous stream of activities, actions, decisions and attitudes that informs decisions about all aspects of life and that reflects existing social norms and processes. There are many classifications of adaptation options summarised in Smit *et al.* (2000) based on their purpose, mode of implementation, or on the institutional form they take.

Coulthard (2009) highlights the difference between adaptations in the face of resource fluctuations that involve diversifying livelihoods in order to maintain a fishery-based livelihood, and those which involve "hanging up our nets", exiting fisheries for a different livelihood source. Another response often observed during the development of a fishery to cope with reduced yield is to intensify fishing by investing *more* resources into the fishery. This can be in terms of increasing fishing effort (by spending more time at sea), increasing fishing capacity (by increasing the number, size or efficiency of gears or technology) or fishing farther or deeper than previously. Such adaptation responses obviously have potentially negative long-term consequences if overexploitation is a concern in the fishery. The state of many of the world's fisheries offers little opportunity for sustainable intensification of fishing as an adaptation strategy.

Inevitably adaptation strategies are location and context specific. Indeed, Morton (2007) argues that both impacts of and adaptation to climate change, will be difficult to model and hence predict, for smallholder or subsistence agricultural systems. This is because of factors such as the integration of agricultural and non agricultural livelihood strategies and exposure to various stressors, ranging from natural stressors to those related to policy change. The same conditions are likely to prevail in the subsistence fisheries sector, though this has not been researched in the same manner as marginal and subsistence agricultural systems. Faced with this complexity there have been various suggestions and typologies of how adaptation actually occurs for such livelihoods.

Adaptation responses can be conceptually organized based on timing and responsibility (see Table 6). Specific adaptations of industrialised fisheries are likely to differ from those of small-scale fisheries. For example Thornton *et al.* (2007) suggest that intensification, diversification and increasing off farm activities are the most common adaptations in pastoralist settings, while Eriksen *et al.* (2005) observe, in addition, the use of greater biodiversity within cropping systems and use of wild foods. In fisheries, analogous responses can be seen as intensifying fisheries, diversifying species targeted or exiting fishing for other livelihoods. Agrawal and Perrin (2007) examine strategies for subsistence resource dependent livelihood systems and suggest all involve functions that pool and share risks through mobility, storage, diversification, communal pooling and exchange. Although most fisheries (even small-scale) are not purely subsistence (Berkes *et al.,* 2001), this typology of adaptation may be useful for conceptualising small scale fishery adaptations to climate change.

5.1 Examples of adaptation in fisheries

Fisher folk and their communities around the world are already constantly adapting to various forms of change (Coulthard, 2009). Thus, much can be learned by examining how fishers have adapted to climate variability such as El Niño and non climate pressures and shocks such as lost markets or new regulations. Table 6 suggests specific adaptations to impacts identified in Table 5. Examples of adaptation in fisheries are dominated by diversification or flexible livelihoods (see Allison, Beveridge and van Brakel, 2008) and migration (Box 9) in response to climate-mediated fluctuations in yield.

Responses to direct impacts of extreme events on fisheries infrastructure and communities are believed to be more effective if they are anticipatory as part of long-term integrated coastal and disaster risk management planning (Nicholls, 2007a). Adaptations to sea level rise and increased storm and surge damage include hard (e.g. sea walls) and soft (e.g. wetland rehabilitation or managed retreat) defences, as well as improved information systems to integrate knowledge from different coastal sectors and predict and plan for appropriate strategies.

Indirect socio-economic impacts are arguably less predictable, making it more difficult to discuss specific adaptation measures. Diversified products and markets would make fisheries less prone to economic shocks, while information technologies are becoming more available to small-scale fishers and may help them to navigate international markets and achieve fair prices for their fish (FAO, 2007b). Generally

TABLE 6
Specific adaptations to climate impacts on fisheries

Impact on fisheries	Potential adaptation measures	Responsibility	Timescale
Reduced fisheries productivity and yields (indirect ecological)	Access higher value markets	Public/private	Either
	Increase effort or fishing power*	Private	Either
Increased variability of yield (indirect ecological)	Diversify livelihood portfolio	Private	Either
	Insurance schemes	Public	Anticipatory
	Precautionary management for resilient ecosystems	Public	Anticipatory
	Implementation of integrated and adaptive management	Public	Anticipatory
Change in distribution of fisheries (indirect ecological)	Private research and development and investments in technologies to predict migration routes and availability of commercial fish stocks*	Private	Anticipatory
	Migration*	Private	Either
Reduced profitability (indirect ecological and socio-economic)	Reduce costs to increase efficiency	Private	Either
	Diversify livelihoods	Private	Either
	Exit the fishery for other livelihoods/investments	Private	Reactive
Increased vulnerability of coastal, riparian and floodplain communities and infrastructure to flooding, sea level and surges (direct)	Hard defences*	Public	Anticipatory
	Managed retreat/ accommodation	Public	Anticipatory
	Rehabilitation and disaster response	Public	Reactive
	Integrated coastal management	Public	Anticipatory
	Infrastructure provision (*e.g.* protecting harbours and landing sites)	Public	Anticipatory
	Early warning systems and education	Public	Anticipatory
	Post-disaster recovery	Public	Reactive
	Assisted migration	Public	Reactive
Increased risks associated with fishing (direct)	Private insurance of capital equipment	Private	Anticipatory
	Adjustments in insurance markets	Private	Reactive
	Insurance underwriting	Public	Reactive
	Weather warning system	Public	Anticipatory
	Investment in improved vessel stability/safety	Private	Anticipatory
	Compensation for impacts	Public	Reactive
Trade and market shocks (indirect socio-economic)	Diversification of markets and products	Private/public	Either
	Information services for anticipation of price and market shocks	Public	Anticipatory
Displacement of population leading to influx of new fishers (indirect socio-economic)	Support for existing local management institutions	Public	Either
Various	Publicly available research and development	Public	Anticipatory

Sources: Categories adapted from Tompkins and Adger (2004) and Smit *et al.* (2000).

Note: *Adaptations to declining/variable yields that directly risk exacerbating overexploitation of fisheries by increasing fishing pressure or impacting habitats.

decreasing the marginalization and vulnerability of small-scale fishers is thought to be an anticipatory adaptation to a range of threats, as well as facilitating sustainable management (FAO, 2007c).

Cultural and socio-economic aspects limit people's adaptive capacity in apparently unpredictable ways. In Pulicat Lake in India, for example, access to fish and prawn fisheries is mediated by caste identities. The non fishing caste members do not have traditional hereditary rights of access and subsequently tend to be economically poorer and more marginalized. However, in the face of declines in catches, these non fishing caste fishers were more adaptable to do jobs outside of the fisheries sector. Hence,

BOX 9

Adaptation of individuals and formal institutions to climate variability in Peruvian scallop fisheries

The Peruvian scallop fishery has been subject to major fluctuations caused by shifts between El Niño/La Niña climate regimes which affect the extent of upwelling and sea temperature off the coast of Peru. Fishers' informal reactive adaptations to these fluctuations are rapid and flexible and mostly involve migration between sites which experience opposite fluctuations in yields as a result of El Niño events. In contrast, formal fisheries management institutions have been slow to respond to fluctuations and show limited capacity to learn from earlier experiences. However, formal institutions are necessary to take account of large-scale and long-term factors to prevent maladaptations like unsustainable levels of effort.

Sources: Badjeck, 2008; Badjeck *et al.* (2009).

they had a greater adaptive capacity and were in many ways less vulnerable to annual fluctuations in stocks (Coulthard, 2006).

5.1.1 Adaptation of fisheries management

Much fisheries management is still loosely based on maximum sustainable yields or similar fixed ideas of the potential productivity of a stock. For example, North Sea groundfish fisheries have recently been managed in order to recover cod to a target biomass of 150 000 tonnes. Although climatic influences on cod productivity are recognised (Anonymous, 2007), there is currently no formal strategy by which environmental processes can be incorporated into management targets and measures. As climatic change increases environmental variation, more fisheries managers will have to explicitly consider such variations and move beyond static management parameters for particular stocks. Such changes create an additional imperative to implement the ecosystem approach to fisheries (EAF), a holistic, integrated, and participatory approach to obtain sustainable fisheries (FAO, 2006).

5.1.2 The role of institutions in adaptation

Institutions, in the broadest sense, mean formal and informal traditions, rules, governance systems, habits, norms and cultures. A technical approach to adaptation can underestimate the importance of institutions (especially informal) to facilitate or limit adaptation. For example, traditional practises or links with alternative livelihoods can be drawn on to adapt to declining fish yields, while cultural identities connected with fishing may limit adaptation, in terms of leaving fisheries, that fisher folk are willing to consider (Coulthard, 2009). An extensive literature documents examples of local resource management institutions that facilitate management of common pool resources and it is proposed that such institutions allow adaptive and sustainable management (e.g. Berkes, Colding and Folke, 2000; Ostrom, 1990). However, in the face of increasing climate change impacts they can also be a barrier to the flexibility needed for adaptive management (Coulthard, 2009). Formal institutions can also constrain adaptation, for example in Peru, the establishment of access rights institutions to improve management of scallop stocks may prevent future migration responses to El Niño shocks (Box 9), while increasing regulation of gears and sectors in Newfoundland fisheries meant that when cod stocks collapsed, cod fishers who previously exploited a range of species, were "locked-in" to the collapsed cod fishery and unable to benefit from expanding shellfish fisheries (Hilborn *et al.*, 2003).

5.2 Building adaptive capacity in fisheries

5.2.1 Uncertainty, surprise and the need for general adaptive capacity

There is great uncertainty in the nature and direction of changes and shocks to fisheries as a result of climate change. Investments in generic adaptive capacity and resilient fisheries systems seem to be a good strategy to support future adaptations which are not currently foreseen. Better managed fisheries with flexible, equitable institutions are expected to have greater adaptive capacity. For example, implementation of the EAF could make an important contribution to adaptation in preparation for the effects of climate change.

Many fishers are vulnerable to a range of disturbances which together decrease their adaptive capacity in the face of climate change impacts (FAO, 2007c,d). Thus, for example, working to address the marginalization of fishing communities and their vulnerability to HIV/AIDS and other diseases and resource insecurity can be seen as a form anticipatory adaptation to climate change shocks.

5.2.2 Have we been here before?

Good management for sustainable stocks, enhanced wellbeing and reduced vulnerability of fisher folk will increase generic adaptive capacity. Therefore, working towards equitable and sustainable fisheries, which has been a goal of fisheries management, may be seen as advancing the adaptive capacity of fishing communities. It has also long been recognized that fisheries management must take account of inherent uncertainty within fisheries which results from climate variability, variable recruitment and unknown linkages within the ecological and social aspects of fisheries (e.g. Charles, 1998).

Thus, adaptation for climate change, in terms of building the resilience of fish stocks and communities and taking account of uncertainty, could be seen as implementation of good fisheries governance as recommended over the past decade, irrespective of climate change, which raises the question of whether new interventions are required to assist adaptation.

Despite the familiarity of the challenges, increased resources and efforts are likely to be needed to adapt fisheries in the face of climate change. The majority of fisheries are still not managed in a sustainable, equitable fashion that takes due account of uncertainty; sudden shifts in systems may result from climate change presenting new challenges; and the magnitude of change may simply overwhelm current options for "good fisheries governance". There may be a need for focused adaptation for poorer, marginalized and most vulnerable fisher folk and communities, which would go beyond previous international development assistance. International financing mechanisms exist and are being developed to support adaptation under the United Nations Framework Convention on Climate Change (UNFCC). These have, for example, funded the creation of National Adaptation Programmes of Action (NAPAs) in poor countries. Significant funds are therefore becoming available for targeted adaptation, but these are thought to be inadequate to address the massive costs of adaptation, while issues of defining and funding adaptation to climate change as distinct from general building of adaptive capacity complicate the process of allocating funds for adaptation (Ayers and Huq, 2009).

6. CONCLUSION

Climate change is predicted to have a wide range of impacts on fisheries and those who depend on them. As is common across climate change science, there is a significant body of knowledge on the biophysical impacts of climate change on aquatic ecosystems, but much less knowledge on how these impacts will be mediated by the socio-economic context of fisheries and how adaptation will proceed. Our sense from this review of knowledge in areas analogous to climate change suggests that impacts resulting from changes in the human context of fisheries (supply, demand, technology and the ability to manage collective resources) will be at least as significant as ecological or direct impacts of climate change on the vulnerability of livelihoods in fishing communities in the near future.

Vulnerability of fisheries to climate change is not only determined by degree of change or impact, but also the sensitivity of individuals or fisheries systems and their adaptive capacity. Adaptive capacity relies on various assets and can be constrained by factors including culture or marginalization. We have reviewed the contribution that the sustainable livelihoods framework can make in representing and objectively measuring the importance of context for understanding the role of fisheries in livelihoods.

The priority responsibility for governments, civil society and international organizations with regard to climate change, is to aggressively pursue reductions in greenhouse gas emissions (GHG), because the long-term consequences of climate change are highly complex, unknowable and potentially irreversible and many already marginalised groups appear most vulnerable to its impacts. Fisheries make a moderate contribution to GHG emissions through fossil-fuel-based catching operations and transportation, which may be reduced with improved technology and management of stocks. Previous global emissions already mean that climate change will affect marine and freshwater systems and fishing communities. Governments therefore have a responsibility to facilitate adaptation, especially for groups vulnerable because of their exposure, sensitivity or lack of adaptive capacity. A research imperative is therefore to:

- identify the most vulnerable individuals and communities;
- investigate possible government facilitated adaptation;
- consider constraints on private adaptations; and
- seek desirable adaptations which contribute to long term reductions in vulnerabilities, rather than short-term coping strategies which may enhance vulnerability.

Reviewing the potential impacts of climate change on fisheries suggests a role for public policy in adaptation: to reduce vulnerability, to provide information for planning and stimulating adaptation and to ensure that adaptation actions do not negatively affect other ecosystem services and the viability of fisheries in the long run.

The first rationale for promoting adaptation is to protect those parts of the fishing sector and communities in coastal areas that have the least ability to cope. Coastal regions facing climate change for example are subject to multiple stresses associated with globalization of fisheries, and in the case of developing countries, lack of public infrastructure, high disease burden and many other factors that limit the ability to adapt.

The second public policy response is the provision of high quality information on the risks, vulnerability and threats posed by climate change. Such information includes scenarios of change at the global scale, but it also involves significant investment in incorporation of climate information into coastal land use planning and other forms of regulation. Hence the need for policy integration across government sectors, such as coastal planning, river basin management, agriculture, fisheries themselves and health and nutrition where climate change risks interact.

The third area of public policy response is in the provision and enhancement of the public good aspects of fisheries and related biodiversity and ecosystem services. The Millennium Ecosystem Assessment highlighted the importance of ecosystem services for human wellbeing. Climate change impacts represent enhanced reasons for sustainable fisheries management and incentives to promote biodiversity conservation within coastal regions, given the potential for habitat decline and species extinction throughout the world.

There is already an imperative to improve fisheries governance to take account of natural variability, uncertainty and sustainability and to address overcapacity and overfishing, which lead to economic losses, endanger future fisheries and degrade aquatic ecosystems (e.g. calls to implement the Ecosystem Approach to Fisheries).

In addition, pro-poor governance of small-scale fisheries is now promoted by international organizations to address marginalization of fishers and equity (FAO, 2005a). These familiar challenges for governance will continue and perhaps become more imperative in the face of climate change. Variability and uncertainty, which have historically been important factors that managers have struggled to take account of, will become more prevalent under climate change. Meanwhile poverty in small-scale fisheries and marginalization of fishers reduces their adaptive capacity.

The wider context of fisheries is also important because of the ways in which politics, socio-economics, demographics, ecology and markets can influence fisheries (and be important pathways for climate change impacts) but also because they are evolving rapidly with processes of globalization. Future climate change will not interact with fisheries in the way it would today because it will affect future fisheries within a future context. This creates additional uncertainty and emphasizes the need for adaptive governance as well as integration of fisheries with other linked sectors, particularly agriculture, which may itself affect fisheries due to climate impacts and adaptation.

Current problems with fisheries management call for strong and reliable institutions governing resource use but, paradoxically, top down or rigid approaches which may seem attractive may not offer the flexibility to ensure resilient fisheries systems and communities under climate change. Approaches such as adaptive co-management, proposed to address uncertainty and harness the knowledge and commitment of resource users at multiple scales (Armitage *et al.,* 2008) may offer the best hopes for resilient fisheries. Experiments with such approaches should be extensively trialled and analysed as a priority. Governance systems with a focus on continual learning from experience, which openly treat policy as experimentation, will be more likely to address new challenges as they arise. Policies which place too much emphasis on stability, certainty and top down control may lead to unexpected consequences and may “lock in” fisheries, preventing desirable and sustainable adaptation.

The process of fisheries and their associated communities adapting to climate change is facilitated and constrained by various social factors and involves value-based decisions and trade-offs. Abandoning fisheries as a livelihood may become a necessary reality in some fisheries. The political and value laden nature of adaptation emphasizes the need for equitable and just deliberative processes, for example, if there is a trade-off between actions and policies that assist the most vulnerable and those which provide optimally efficient adaptation or large-scale resilience.

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