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Effects of climate change on the sustainability of capture and enhancement fisheries important to the poor: analysis of the vulnerability and adaptability of fisherfolk living in poverty

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ADMINISTRATIVE DETAILS

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TITLE OF PROJECT	Vulnerability of fisherfolk living in poverty to climate change
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1. EXECUTIVE SUMMARY

1.1 Importance and vulnerability of small-scale fisheries

The majority of the world's 200 million full and part-time fisherfolk (fishers, fish processors, traders and ancilliary workers) and their dependents live in areas vulnerable to human-induced climate change, or depend for a major part of their livelihood on resources whose distribution and productivity are known to be influenced by climate variation. However, relationships between the biophysical impacts of climate change and the livelihood vulnerability of poor fishing communities have seldom been investigated. Information has been lacking on the areas and people that are likely to be most vulnerable to climate-induced changes in the fisheries. This information is required for the effective prioritisation of development interventions to reduce vulnerability to the impacts of adverse climate change on fisherfolk living in poverty.

The fisheries sector makes important contributions to local development in coastal, lakeshore, floodplain and riparian areas, through employment and multiplier effects. Maintaining or enhancing the benefits of fisheries in the context of a changing climate regime is an important development challenge.

1.2 Project purpose

The purpose of the project was to explore the potential impact of climate change on the sustainability of capture and enhancement fisheries important to poor people with a view to informing the development of a research agenda in this field. The project has provided a synthesis of current thinking on the relations between climate change, vulnerability and adaptation of poor fisherfolk and has provided the outline for a research agenda to enable fisheries agencies and other stakeholders to respond to the challenges posed by rapid climate change.

1.3 Poverty and small-scale fisheries

Recent analysis of poverty in small-scale fisheries, guided by the sustainable livelihoods analytical framework, has identified vulnerability to external shocks and trends, rather than asset or income poverty, as a particular threat to the sustainability of fishing-based livelihoods. These external shocks and trends include climate change, variation and extreme events. High levels of vulnerability potentially undermine the important contributions made by fisheries to poverty alleviation and nutritional security at local, regional and sometimes national levels

1.4 The threat of climate change

It is widely accepted that at least part of the earth's 0.6°C warming during the last 100 years is due to emissions of greenhouse gases caused by human activities. During this century, the world is expected to continue warming, by between 1.4 and 5.8°C. Other predicted impacts by 2100 are a rise in average global sea level of between 0.1 and 0.9 m and changes in weather patterns, including an increased frequency and severity of extreme events such as hurricanes, floods and droughts

Regional patterns of precipitation, storm intensity and sea level rise are much more difficult to predict than global trends and patterns are different between different Global Circulation Models. Mean sea level rise will lead to extreme levels being reached more frequently and changes in storm surge heights may result from increases in strong winds and low pressure events.

The oceanic circulation system is also likely to be strongly influenced by warming, with likelihood of increased frequency of El Niño Southern Oscillation (ENSO) events affecting current-dependent upwelling fisheries, including the major industrial fisheries for small-pelagic fish, with consequences for global fish supplies.

Although resource-dependent communities in the developing world have adapted to climate variability throughout history, through maintaining occupational and geographical mobility, projected climate change poses multiple risks to fishery-dependent communities because of the increased frequency of extreme weather events, the potential for large-scale phase shifts, and from risks that lie outside the realm of present day experience. It is also no longer always possible for fisherfolk to fall back on historical adaptive strategies due to increasing coastal and riparian populations, reduced fish catch rates and institutional barriers preventing or reducing the ease of geographical and occupational mobility.

The multiple stresses associated with coastal urbanization, changes in the frequency and intensity of coastal storms and hurricanes, and the impacts of climate change on sensitive coastal ecosystems such as coral reefs and mangroves make this a key issue of concern for vulnerability and security of resource-dependent communities.

In the important inland lake and floodplain fisheries, dynamics of fisheries are driven primarily by climate variations and both the ecosystems and the livelihoods of fisherfolk living near these waterbodies are highly adapted to extensive fluctuations. These systems are therefore particularly climate-change sensitive.

1.5 Pathways of impact of climate change on fisheries

Climate change will impact on fisheries through a diversity of direct and indirect pathways whose importance will vary depending on the type of ecosystem and fishery. Inland fisheries, particularly important for small-scale fishers in developing countries and an integral part of many rural livelihood systems, will be severely impacted by changing water levels and flooding events, while coastal marine fisheries dependent on sensitive ecosystems such as coral reefs will be impacted by rising water temperature that affects ecosystem functions.

Some of the pathways identified in this study are impacts of:

- sea temperature change on aquatic ecology: shifting range of fish species, change in ocean currents affecting upwelling zone fisheries, coral bleaching affecting reef fisheries, disruption to fish reproductive patterns and migratory routes
- precipitation and evapotranspiration change on hydrology of inland waters: river flows and flood timing and extent change, affecting fish reproduction, growth and mortality, as well as other elements of wetland-based livelihoods (agriculture, pastoralism, forestry etc).
- Increased frequency of extreme events: more frequent loss of fishing days due to bad weather, increasing loss of nets, traps and longlines, damage to boats and shore facilities, increased loss of life among fishermen, increase damage to coastal communities – houses, farmland etc.

1.6 Defining and measuring vulnerability to climate change

Vulnerability is the extent to which climate change may damage or harm a system; it depends not only on a system's sensitivity, but also its ability to adapt to new climatic conditions (IPCC, 2001). In the social realm vulnerability can be defined as the exposure of groups or individuals to stress as a result of climate variability and change. It complements notions of physical vulnerability to the impacts of natural hazards that concentrate on the physical dimensions of risk. Vulnerability is therefore made up of a number of components including exposure and sensitivity to hazard and the capacity to adapt:

$$\text{Vulnerability} = f(\text{exposure, sensitivity, adaptive capacity})$$

Adaptive capacity has diverse elements encompassing the capacity to modify exposure to risks associated with climate change, absorb and recover from losses stemming from climate impacts, and exploit new opportunities that arise in the process of adaptation.

1.7 Global analysis of vulnerability of the fisheries sector to projected climate change

This project set out to use the 2001 Intergovernmental Panel on Climate Change (IPCC) scenarios for global temperature rise to 2050 to assess the vulnerability of fisherfolk to projected climate change on a global level, with the objectives of highlighting the extent of the possible impacts and to identify 'hotspots' – regions and countries where the impacts of climate change would be expected to be severe.

The analysis was conducted at country-level using IPCC climate change scenarios, parameterised with data from the Hadley Centre model, re-scaled to national political boundaries. 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 GDP are assumed to have higher adaptive capacity. Because poverty data are not widely available for fisherfolk, it was necessary to use national-level averages and assume the distribution of poverty was similar to the average national distribution.

A global database of risk exposure and different elements of sensitivity and adaptive capacity was assembled and analysed to compute vulnerability. Maps showing the global distribution of some of the key variables were developed.

Global climate change scenarios from IPCC suggest that the Asian landmass, the Amazon basin and the Western Sahara are the regions most at risk from climate change (highest predicted temperature change). The level and distribution of projected change varies according to different scenarios for economic growth.

The largest number of poor fisherfolk are likely to be found in South and South East Asia, where the majority (over 80%) of the world's fisherfolk are to be found. Although fisherfolk are fewer in Africa, the low per capita GDP of most African countries means that it is likely there are significant numbers of fisherfolk living in poverty. In Latin America, Colombia, Guyana, Bolivia and Honduras are the poor countries with significant employment in the fisheries sector.

Many of the most nutritionally dependent countries are small island states. The populous major fishing nations of Ghana, Indonesia and Bangladesh are also represented.

Combining economic dependency indices (production and trade), nutritional index and number of fisherfolk living in poverty leads to a composite index of sensitivity of the fisheries sector to climate change. The most sensitive countries are, in Asia; China, Indonesia, India and Vietnam; in Africa, Mauritania; and in Latin America, Peru. Iceland is the most sensitive country in the developed world

Combining risk exposure, sensitivity and adaptive capacity gives a composite index of vulnerability. The analysis shows that it is African countries whose fishery sectors and fishing people are most vulnerable to climate change (see table overleaf) and that it is those semi-arid countries with significant coastal or inland fisheries that will be most vulnerable. Among the non-African countries, only the Russian Federation and Peru appear in the top fifteen most vulnerable. Which IPCC scenario is chosen makes relatively little difference to the results. Poor countries with important fisheries such as Angola and Mauritania top both lists.

Countries with the highest projected indices of vulnerability of fisheries to climate change under two different IPCC future climate change scenarios

Rapid Development, High Emissions Scenario (IPCC A1F1)		Local Development, Lower Emissions Scenario (IPCC B2)	
Angola	81.97	Mauritania	83.10
Mauritania	81.18	Angola	82.15
Niger	79.24	Zimbabwe	79.32
Congo, Dem Rep	78.82	Niger	78.95
Mali	78.01	Congo, Dem Rep	76.03
Sierra Leone	77.09	Mali	75.92
Burkina Faso	76.01	Mozambique	75.13
Burundi	74.96	Russian Federation	74.33
Mozambique	74.86	Sierra Leone	73.61
Zimbabwe	74.55	Senegal	73.31
Senegal	73.70	Botswana	72.96
Guinea-Bissau	72.97	Zambia	71.78
Côte d'Ivoire	71.18	Burundi	71.68
Sudan	70.68	Burkina Faso	71.57
Russian Federation	70.57	Peru	70.98

The indices have their limitations. Principal among these are the reliance on air temperature change as a risk-exposure variable. In aquatic systems, precipitation and sea/water temperature change would be more appropriate, but these variables are less available on a global scale.

Despite its shortcomings, the analysis has provided a testable methodology for vulnerability assessment and has produced results that may surprise and stimulate new analysis.

1.8 Case studies of sensitive areas/ecosystems

Because the pathways linking climate change to vulnerability of fisherfolk are so diverse, the global analysis was supplemented by a series of specific area or ecosystem based case studies to illustrate the type of issues that might be confronted by attempts to support vulnerability reduction programmes targeted at fisherfolk. No unified 'method' was imposed for these studies and they represent a snapshot of current research efforts in the field.

1.8.1 Coral Reefs

Thermal bleaching along with fisheries exploitation, pollution and disease are the greatest threats to coral reefs. Coral reefs are a major source of ecosystem goods and services, particularly for small island developing states. Tens of millions of people in over 100 countries are likely to depend on coral reefs for part of their livelihood or for part of their protein intake.

The aim of this case study analysis was to analyse the link between the per capita fish consumption of fisherfolk and the potential supply and demand of reef resources at national scales, taking projected population growth and projected climate change into account.

The relative effect of projected human population growth and loss of coral reef area on per capita fish consumption are compared from 2000 – 2015. Projected human population growth is predicted to reduce per capita fish consumption by 0.88% year^{-1} and the loss of coral reef area due to climate-change induced bleaching is predicted to reduce per capita fish consumption by 0.1-0.3% year^{-1}. The highest rate of reduction in per capita fish consumption is based on a loss of coral reef area of 1% year^{-1}.

1.8.2 African Lakes

The African Great Lakes region harbour important fisheries that contribute to employment, food security, government tax revenues, domestic markets and exports. The production systems of these lakes are known to be climate-sensitive.

For the extensive shallow lake-wetland complexes such as Lakes Chad, Kyoga and Chilwa, analyses of links between rainfall variation, lake levels and fish catches indicate that predicted reductions in rainfall in some regions are likely to result in significant reduction of lake and wetland area, with resulting large reductions in fish production and supply, particularly in the case of wetlands in arid and semi-arid areas. With the resilience of these production systems partly dependent on the existance of dry season refugia for fish, increasing duration of the dry seasons and increased number of drought years, forecast in some regional climate models, is likely to result in reduced resilience of these lakes and increased pressure on dry-season refugia.

In the large rift valley lakes with significant fisheries for small pelagic species, climate-associated changes in their productivity has apparently led to reduced fish production.

Livelihoods around these lakes combine farming and fishing, and with both negatively affected by rainfall reduction, if regional climate forecasts are accurate, it seems likely that rural livelihoods in lakeshore regions will become more precarious and less viable over time. Migration from lake to lake, and from lakeshore regions to cities and other areas of economic opportunity is already common in the region. These migrations are likely to increase as rainfall variability increases.

1.8.3 River basins and floodplains - Bangladesh

The biology and ecology of fish in large rivers are strongly linked to the hydrological regime in the main channel and the regular flooding of their adjacent floodplains. The absolute and relative abundance and biomass of species of fish inhabiting large rivers are predicted to change in response to both natural intra-annual variations in flooding regimes as well as long-term climatic shifts.

Using an age-structured population dynamics model we explored how hydrological conditions within a theoretical floodplain river system may affect the dynamics and exploitable biomass of fish of the type that dominate catches in Bangladesh and also in the Tonle Sap and Lower Mekong rivers, which have common characteristics including rapid growth, small maximum size and sexual maturation by the end of their first year. Model simulations suggest that exploitable biomass is predicted to increase with increasing hydrological stability. Conversely, diminished and less stable flooding conditions would be expected to reduce exploitable biomass.

The implications of these simulation results were explored by combining their insights with knowledge of the fisheries sector in Bangladesh, where both the fisheries and agricultural sectors of the economy rely heavily upon the seasonal rainfall and floodplain inundation for their production. The results are ambiguous and depend on how other sectors – flood control and irrigation, for example - react to climate-induced change.

Any reductions in fisheries production will require fishers to further diversify their activities and flexibly exploit resources as they become available. Their vulnerability to change will largely be a function of their capacity to adapt. Their ability to adapt is, however, largely constrained by their paucity of financial and human capital. Their typically poor health and inadequate health care systems makes them further vulnerable to extreme events and outbreaks of disease.

1.9 Dissemination of results and recommendations

The project was essentially a scoping study and literature review, although significant analysis of available data has taken place. The work will feed into a synthesis of contributions of FMSP, ASP and RNRS projects to understanding vulnerability of fisherfolk and others living at the land-water interface, to enable agencies involved in fisheries management and development to respond in ways that help to build adaptive capacity. This dissemination-focused project has begun, and involves some of the project team that contributed to this report.

The results of the analysis and scoping study will also be submitted for publication in the peer-reviewed scientific and development literatures.

1.10 Recommendations for future research

The analysis in this report provides a basis for targeting future interventions to support adaptation to future climate change among poor fisherfolk and in fishing-dependent regions but there remain several key knowledge-gaps that constrain our ability to advise on appropriate means to implement such interventions. These knowledge gaps are briefly summarised here. They could form the basis for a future research agenda in this field.

1.10.1 Improving global and regional vulnerability assessments

This project has developed a methodology for preliminary analysis of vulnerability of poor fisherfolk to climate change, using available national-level data to produce the first global assessment of this issue. There are a number of possible improvements that can be suggested to develop vulnerability assessments that can be defended with greater confidence. At regional level, we have outlined a number of case-studies that illustrate how climate change, physical habitat change could be related to ecological and livelihood responses and coping ability or resilience. Suggestions to improve parameterisation of these assessments, as well as alternative or complementary assessment methods, are given below.

Researchable constraints:
Lack of appropriate methodology and limited availability of appropriate data for vulnerability assessment to identify priority areas for action.

Suggested Research areas:

a. Improving parameterisation of 'risk exposure' to climate change

- Exploring the effects of including projected changes in precipitation in vulnerability analyses - particularly for inland fisheries.
- Incorporating additional environmental factors into vulnerability assessments - such as storm and flood frequencies (based on historic observations), and sea level rise (on a case study basis, for areas where regional models exist).

b. Improving parameterisation of sensitivity and adaptive capacity

- Using regional demographic data (e.g. global database on the number of people who live within 100 km of the coast, and the number of those living in poverty) to refine some of the indices of sensitivity and adaptive capacity currently calculated at national level.
- Obtain data on poverty and HDIs specific to fisherfolk. Developing a suitable set of indicators of sensitivity and adaptive capacity for both national and regional-level assessments is a key requirement for any future assessment of vulnerability.
- Incorporate future changes in socioeconomic parameters (e.g. demographic change, projected HDI and poverty data), reflecting the assumptions that underlie the various IPCC scenarios. At present, we have projected climate change (i.e. risk exposure) but have used current values, rather than projected values, for sensitivity and adaptive capacity.

The outputs of these research activities would be improved assessments of vulnerability to provide a better basis for planned interventions to support adaptation strategies.

c. Using ‘expert elicitation techniques’ to assess global and regional risks of climate change to fisheries and livelihoods.

Much global scale analysis of exposure risks from climate change relies on modelling techniques that struggle to capture the complexities of social and ecological processes. Often, relevant data on climate variables are missing. An alternative rapid assessment technique to assess global or regional risks involves use of expert elicitation techniques, used in health, climate and other risk fields. A strategic assessment of the relative importance of risks in this area, compared to other stressors on fisheries sectors, could be undertaken to quantify specified risks. Such analyses are increasingly influential in framing future risk strategies that involve deep uncertainties.

d. Developing methods of vulnerability analysis for fisheries at different scales.

Development and well-being trends are linked to vulnerability and exposure to climate change impacts can exacerbate vulnerability but the processes that link risk exposure to vulnerability are not well understood across scales. The relationship between climate and environmental drivers with other multiple stressors is also not understood. The benefits of this research would be a more precise targeting of adaptation action and interventions to the most vulnerable fisheries systems.

1.10.2 Research needs for vulnerable fishery systems

Some fishery systems (coupled social-ecological systems) are shown to be particularly sensitive to future climate change. Such systems that also support significant fisheries supporting the livelihoods of the poor are: coral reefs and associated habitats (eelgrass beds and mangroves), fisheries in inland waters that are highly dependent on climate-driven variations in hydrology (e.g. shallow lakes, river floodplains), and coastal pelagic zones (including upwelling areas accessible to small-boat fisheries) Low human adaptive capacity (weak economies, low human development indices) appear to make fishery-dependent African countries particularly vulnerable.

Researchable Constraints:

Insufficient understanding of the links between projected climate change, environmental responses, fish stock and aquatic ecosystem responses, livelihood impacts and responses, and the adaptive capacity of institutions, at scales relevant to fisheries management (e.g. coastal zone, reef, large marine ecosystem, river basin, lake catchment)

Research priorities:

Focused studies on risk exposure, livelihood sensitivity and peoples’ vulnerability, including:

a. Research on adaptive fisheries management in identified vulnerability hotspots
b. Analsyis of vulnerability of the poor dependent on coral reef systems

c. Assessing resilience and vulnerability in Inland Fisheries, in the context of water resources management
d. Analysis of adaptive capacity to change in climate-sensitive coastal small-scale fisheries in West Africa and S/SE Asian nations with important fishery sectors

1.11 Conclusion

The outputs of the research proposed above would provide information for management decision-making and development intervention specific to particular types of fishery. These fishery types are those that are particularly important to small-scale fisheries, where the largest numbers of the poor are found. Together with existing work, they would provide a firm basis upon which to integrate climate science with development needs.

Recent analysis of global climate models show that, even if the concentrations of greenhouse gases in the atmosphere had been stabilized in the year 2000, we are already committed to further global warming of about another half degree and an additional 320 % sea level rise caused by thermal expansion by the end of the 21st Century. This means that, whatever progress is made over the coming decades in climate change mitigation, it will be necessary to plan and adapt for impacts of unstoppable change. It seems appropriate to give prominence in the response to global climate change to those people whose lives depend so directly on the rising and receding waters that the coming century will bring.

2 BACKGROUND

2.1. Poverty and fisheries management and development – the global context

It is now estimated that in South Asia and Sub-Saharan Africa over two hundred million people depend on fish, either directly or indirectly, for employment (FAO, 2004). With capture fisheries no longer expanding and the proportion of overexploited and depleted stocks having risen from about 10 percent in the mid 1970s to around 25% in the early 2000s, the potential for fisheries to contribute to poverty alleviation and vulnerability reduction is becoming more limited. Aquaculture development is projected to fill some of the food supply gap created by declining or stabilising capture fisheries yields and increasing human population (FAO, 2004), but aquaculture development does not necessarily involve the poor, or indeed, people from the fisheries capture sector.

In the context of heavily exploited fisheries, the impacts of climate change and variability are put sharply into relief. A fluctuation in the biological production of the marine or aquatic environment, induced by increased climate variability and climate change, is felt acutely in fishery systems where a large share of total production is captured to support people’s livelihoods. The impacts of climate change on the links between production and livelihoods are therefore likely to be significant.

The role of small-scale fisheries in meeting food-security needs and contributing to livelihoods in developing countries is increasingly recognised. Past development and management emphasised ‘scaling-up’ fisheries by programmes for industrialisation and centralisation of capture, landing, processing and marketing sectors (Cycon, 1986). Institutional development focused on increasing state-based research, monitoring and enforcement capability (Mahon, 1997). Since the introduction of the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) many of these processes have been reversed, and there is now more emphasis in developing country fisheries on environmental sustainability issues, maintaining fisheries-based livelihoods, food security and distribution networks, and decentralised or community-based management (Payne, 2000).

This shift in emphasis follows partly from a perceived crisis in world fisheries (summarised in Box 2.1) and partly from recently improved alignment of fishery sector development goals with the broader poverty-focused development agenda encapsulated in the millennium development goals.

The vast majority of the worlds’ fisherfolk are involved in small-scale or artisanal fisheries in developing countries. The contribution of small-scale fisheries and aquaculture in developing countries to global fish production continues to increase (Figure 2.1), with 68.1% of production now coming from developing countries.

Box 2.1. Fisheries production and the state of world fisheries (from FAO, 2004)

Total world fishery production in 2002 was about 101 million tonnes of food fish in 2002, providing an apparent global per capita supply of 16.2 kg (live weight equivalent). Additionally, some 32 million tonnes of marine products with non-food uses (mainly fish meal and oil) were produced. Global landings from capture fisheries have remained relatively stable in the four years 1999-2002, at around 93 million tonnes, with the global aquaculture production increasing from around 30 to 40 million tonnes during the same period. The top 10 fish producing nations are China, Peru, the US, Indonesia, Japan, Chile, India, the Russian Federation, Thailand and Norway.

World marine capture fisheries production dropped to 78 million tonnes in 1998, representing a 9 percent decline with respect to the all-time production highs of about 86 million tonnes in 1996 and 1997. The decline appears to have been caused essentially by climatic conditions. Since 1999, marine capture fisheries have been more stable at around 85 million tonnes, although there has been considerable regional variation. Although final figures for 2003 are not available, the decline in Peruvian anchoveta catches will probably lead to a final figure some 3 million tonnes lower than that for 2002.

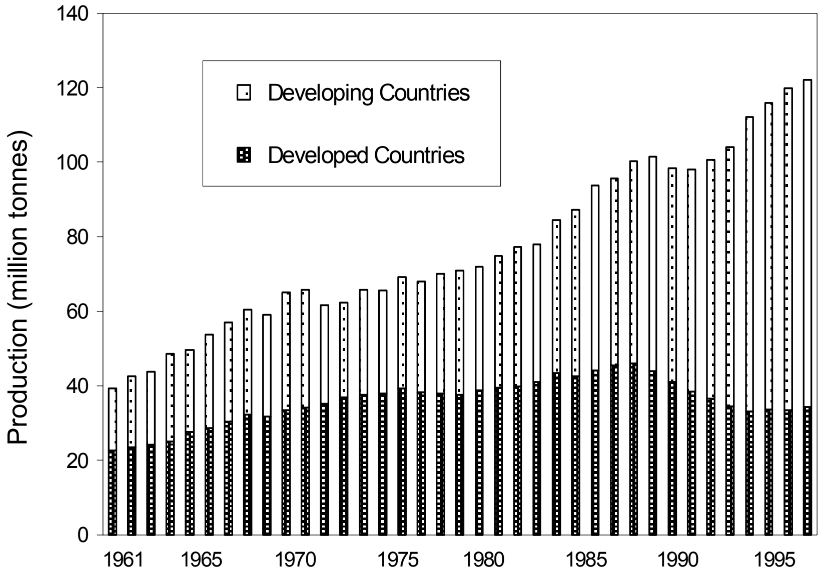
Inland aquatic resources are under pressure from loss or degradation of habitat and overfishing, but it is extremely difficult to assess the state of inland fisheries resources because reporting does not include all the sectors of the fishery and catch is seldom broken down by species. Production is around 8.7 million tonnes per year, with the major producers being China (26% of total production), India, Bangladesh, Cambodia, Indonesia, Myanmar, Egypt, Tanzania, Uganda and Brazil (decreasing from 9% to 2.5% of total production). These ten countries account for 66% of global inland fisheries production, and Africa and Asia together account for over 90% of inland capture fisheries production.

Exploitation status: Among the major marine fish stocks or groups of stocks for which information is available, an estimated 25 percent are under-exploited or moderately exploited. About 52 percent of stocks are fully exploited. Another 16 percent are overexploited and have no potential for further increase. The remaining 7percent of stocks have been depleted, with perhaps 1 percent now recovering from depletion.

Employment in the primary capture fisheries and aquaculture production sectors is estimated to have been about 38 million people in 2002, – about 2.8% of the 1.33 billion people involved in agriculture worldwide. The majority (29 million) are involved in capture fisheries production on a full or part-time basis. Over 120 million people were involved in activities relating directly to capture, processing and sale of fish; 95% of them are in developing countries. Of the world's fishing populations, 87% are in Asia and 7% in Africa. Employment in inland and marine aquaculture has been increasing, and is now estimated to account for about 25 percent of the total. Marine capture fisheries account for about 60 percent and inland capture fisheries for the remaining 15 percent.

While aggregate employment and production figures in developing-country fisheries are at all-time highs, there is evidence that many fisheries are overexploited (see Box 2.1). There are also indications that the number of people employed in the sector has begun to level off over the last five years, despite continuing population increase (Tietze, 2000).

Figure 2.1. Global fish production (millions of metric tonnes) from developed and developing countries. (FAO, 2000). Production figures include farmed fish, non-fish marine products (e.g. molluscs and crustacea), and inland fisheries.



In terms of supply (Delgado et al., 2004), the share of developing country fish consumption rose from 45% in 1973 to 70% in 1997, but, for example, levels of per capita fish consumption have hardly increased in SSA over the past 30 years, and have actually decreased since the mid-1980s. Fish accounts for 20% of animal protein consumed in low-income food deficit countries as opposed to 13% in industrialized countries, but the absolute levels of fish consumption in developing countries are still lower than in developed countries

The relative poverty status of fisherfolk remains largely unknown, but where local and regional case-studies have been undertaken, it is often found that fisherfolks' incomes are higher than those of other rural dwellers (Allison, 2005; Béné et al., in press). Fishery sector earnings are, however, highly uncertain, often seasonal, and are not evenly distributed within the sector; fishers who own boats and/or fishing gear earn substantially more, in terms of net income, than crew labourers paid a share of the value of the catch.

Income and capital or physical asset ownership are not, however, the only dimensions of poverty. There is an emerging body of literature (reviewed in Allison, 2005; Allison & Horemans, 2005; Béné et al., 2005) that highlights fisherfolks' deprivation in terms of access to services (such as health and education), lack of rights over land and water, limited political representation and widespread social marginalisation, sometimes including active discrimination. Within fishing communities, there are also often marked gender disparities, with women typically occupying lower-margin economic activities and being excluded from management decision-making structures at community level.

The high levels of uncertainty and marginalisation in many developing-country fishing communities are often most evident in the context of vulnerability. Fishing livelihoods may be profitable but precarious in conditions where future production is uncertain in the longterm and fluctuates extensively in the short-term, where access rights over resources are insecure, working conditions unsafe and exploitative, and where there is a lack of social and political support for community development and poverty allevation. It is in this 'risk environment' that the added stress of future climate change takes place.

With the emerging evidence that fisherfolk are seldom 'the poorest of the poor' (at least in terms of income) but that they suffer high levels of non-income poverty and vulnerability, has also come a greater appreciation of the role that small-scale fisheries play in the rural or agricultural and national economy of many of the world's poorer and more populous countries. Fisheries contribute significantly to employment, provision of food, generation of revenues for local and national government from licences and taxation on landings, from export revenues, and from various upstream and downstream multipliers (reviewed in Béné et al., in press). Often, fish landing beaches and ports are centres of the cash economy in areas otherwise remote from the market; they stimulate the kind of monetisation of the rural economy that is seen by current mainstream development policy makers (e.g. in the form of poverty reduction strategy plans) as the means to reduce rural poverty. In small island states and fishery dependent regions of larger economies, the sector is a significant contributor to the overall economy and society.

The multiple benefits that fisheries contribute to poverty alleviation are threatened by climate change that either increases uncertainty (thereby reducing the incentives for long-term management of resources) or decreases production – or both. It is therefore important to understand how climate change might impact the poverty alleviation function of fisheries and how this impact might be reduced through appropriate development interventions at policy, programme and project levels.

2.2 Climate change scenarios and aquatic, coastal and riparian environments

Climate change contributes to the uncertainty inherent in fisheries systems (Flaaten et al., 1998) – an uncertainty compounded by the difficulties of predicting future climate change. While the reliability of current projections on climate change is questioned in some quarters (e.g. see Sharp, 2003, for a review in the fisheries context), this report follows the scientific consensus view, as espoused by the Intergovernmental Panel on Climate Change (IPCC).

2.2.1 Global climate change

It is widely accepted that at least part of the earth's 0.6°C warming during the last 100 years is due to emissions of greenhouse gases caused by human activities. During this century, the world is expected to continue warming, by between 1.4 and 5.8°C. Other predicted impacts by 2100 are a rise in global sea level of between 0.1 and 0.9m and changes in weather patterns, including an increased frequency and severity of extreme events such as hurricanes, floods and droughts. During the last few years, scientific consensus has moved to an acceptance that climate change is 'real' and that we are now experiencing its early stages. In 2001, the Intergovernmental Panel on Climate Change (IPCC), which reflects the international scientific community on climate change, stated that "most of the warming over the last 50 years is attributable to human activities" (IPCC, 2001).

The most physically realistic and widely used approach for projecting the details of how the climate system may respond to increased concentrations of greenhouse gases is to use computer simulation models known as general circulation models (GCMs). The most sophisticated of these couple atmospheric and oceanic components into fully coupled Atmosphere-Ocean GCMs. In this analysis we use results from a state of the art coupled Atmosphere-Ocean GCM – the UK Hadley Centre GCM, HadCM3 (details given in Section 4.3). The results of our global analysis of risk exposure to climate change, described in Section 5.3, are developed using the scenario projections developed from this model.

There are some aspects of future climate change with which we have greater confidence than others. For example, we are more confident about increases in greenhouse gas concentrations and rises in sea-level than we are about increases in storminess and the behaviour of the El Niño-Southern Oscillation (ENSO). The scenarios for temperature rise presented in this report are derived from a GCM that includes the best possible representation of processes in the atmosphere, ocean and land, given present scientific knowledge and computing technology. Nevertheless there is varying degree of uncertainty associated with different climate variables which affects the level of confidence in their results.

The main sources of uncertainty result from: future emissions and atmospheric concentrations of greenhouse gases; incomplete knowledge about how the global climate system will respond to greenhouse gas forcing; natural variability due to the tendency of a system to be sensitive to its starting conditions, which can create uncertainty at a later time; and the reduced confidence in GCM results at the detailed spatial and temporal scales often required by planners and managers. One outcome of this uncertainty is that different climate models sometimes yield different regional climate responses to the same greenhouse gas emissions, producing an additional measure of uncertainty in future climate scenarios. Differences between models are associated with not knowing how the climate system reacts to unprecedented rates of greenhouse gas emissions or in knowing how clouds, forest, grasslands or particularly the world's oceans react to climate perturbations and how they feed back into the system. This uncertainty is not directly considered in this report because we use results from one GCM. It should, therefore, be clearly recognised that the results in Section 4 should not be treated as predictions, but that they represent one scenario or projection of future climate conditions out of a wide range available and an even wider range of physically possible conditions. For HadCM3 details of the model and emissions scenarios are described in Gordon et al. (2000) and summarised in Section 4.3. Use of these GCM outputs as the basis for future climate change scenarios for the UK is explained in Hulme et al. (2002) and a wider discussion of the use and meaning of scenarios derived from GCMs appears in MacCracken et al. (2003).

Given the uncertainties and the range of GCM scenarios for the future the models do produce consistent results for aspects of the coupled atmosphere-ocean system. These are fully reviewed in IPCC (2001) and the results relevant to fisheries are summarized in the following section.

2.2.2 Changes in atmospheric components

Along with global warming and sea level rise the key changes in extreme weather and climate events include those that are consistently predicted by most GCMs (summarized in Table 2.1, adapted from IPCC, (2001)). Global temperature rise of 1.4 to 5.8°C from 1990 to 2100 is expected which is a greater rate than the last 50 years and possibly during the last 10,000 years. Land areas, particularly northern high latitudes in winter, warm more rapidly. South and southeast Asia and southern South America warm less rapidly than the global mean change (IPCC, 2001).

In terms of precipitation the regional changes are less certain but larger year to year variations are very likely in areas where increases are projected. More intense precipitation events are very likely, over many areas, as the ability of the atmosphere to hold more moisture increases (IPCC, 2001). Evidence of increasing frequency of high intensity precipitation events is accumulating (see, for example, Osborn and Hulme (2002)).

Table 2.1 Estimates of confidence in projected changes in extreme weather and climate events (adapted from IPCC, 2001).

Changes in phenomenon	**Confidence in projected changes**
Higher maximum temperatures and more hot days over nearly all land areas	Very likely
Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely
Reduced diurnal temperature range over most land areas	Very likely
Increase of heat index over land areas	Very likely, over most areas
More intense precipitation events	Very likely, over many areas
Increased summer continental drying and associated risk of drought	Likely, over most mid-latitude continental interiors
Increase in tropical cyclone peak wind intensities	Likely, over some areas
Increase in tropical cyclone mean and peak precipitation intensities	Likely, over some areas

For society - and for fishing communities and fisherfolk in this case - a critical question is whether and how the frequency and severity of extreme events will change in the future? As the level of spatial and temporal detail increases in GCMs, their ability to model realistically and produce reliable projections decreases. This means that many severe weather phenomena such as tornadoes, hail and lightning are not simulated in GCMs and so there is no clear indication of how they may change in the future. Larger-scale features such as extra-tropical storms and tropical cyclones are represented, although still with high uncertainty. IPPC (2001) concluded that changes in peak wind intensities have not yet been observed and there are insufficient data to assess changes in precitation intensities. According to IPCC (2001) some GCMs suggested an increase in tropical storm wind and precipitation intensities and a more recent studies by Knutson and Tuleya (2004) confirms and reinforces these results. They demonstrate using nine different GCMs that increasing concentration of greenhouse gases (CO_2) over an 80-year period produced an average increase in hurricane intensity which could lead to an increasing risk in the occurrence of highly destructive category-5 storms and an 18% increase in precipitation near the hurricane core.

2.2.3 Changes in sea level

During this century the largest contribution to sea level rise is expected to come from thermal expansion with smaller contributions from melting land ice. Observations suggest sea surface temperatures have increased 0.4 to 0.8°C since the late 19th century and global ocean heat content has increased by 0.04°C/decade since the 1950s (IPCC, 2001). IPCC (2001) infer a rate of global mean sea level rise during the 20th century in the range 1.0 to 2.0mm/year and their projections of global sea level rise are given for two future periods in Table 2. Regional patterns of sea level rise are much more difficult to predict and patterns are different between different GCMs (Gregory et al., 2001; Bigg et al., 2003). Bigg et al. (2003) summarize the results that are consistent between GCMs as follows: above-average Arctic sea level rise due to Arctic freshening; a Southern Ocean minimum poleward of 60°S and; a reduced rise south of the Gulf Stream and elevated rise in the north due to weakening of the Thermohaline circulation. Mean sea level rise will lead to extreme levels being reached more frequently and, more significantly, changes in storm surge heights may result from increases in strong winds and low pressure events (e.g. rising hurricane intensity discussed above), (Gregory et al., 2001).

Table 2.2. Estimated envelope of change in global mean temperature and sea level rise, 2015 and 2050, from IPCC (2001).

	Global temperature change	Global sea level rise
2015	0.20 - 0.70°C	0.04 - 0.06m
2050	0.75 - 2.50°C	0.08 - 0.25 m

2.2.4 Coupled atmosphere-ocean changes – ENSO and the Thermohaline circulation

The significant influence of ENSO on fisheries has been well documented. Later sections draw attention to specific case studies where large scale variability due to ENSO has significant effects on fisheries production. Future behaviour of ENSO will be critical to the manifestation of climate change and its effects on availability and accessibility of fish. There has been considerable study of long-term observed changes in ENSO during the 20th century (see for example Trenberth and Hoar, 1996 and subsequent discussion, e.g. Wunsch, 1999). Some argue for real changes in ENSO frequency and severity while others argue that changes are just part of natural variability. For the future, the issue is even more uncertain as most coupled GCMs do not simulate ENSO variability very convincingly (IPCC, 2001). GCMs present, therefore, a wide range of possible ENSO changes, but first order effects would suggest the recent observed variability is more likely to continue than return to the less frequent and severe events of the 1931-60 period. Some studies point towards increasingly frequency of ENSO-like conditions (Timmerman et al., 1999). Lack of consistency between models also applies to changes in behaviour of other important atmosphere-ocean features of decadal variability such as the North Atlantic Oscillation, the Antarctic Oscillation and the Arctic Oscillation.

There is great concern about the possibility of weakening in the Thermohaline circulation due to CO_2-induced warming. Significant changes in the Thermohaline circulation would change the global radiation budget, produce huge climatic changes and nutrient circulation changes. Weakening is found in most coupled GCM experiments in both the Northern and Southern Hemispheres without incorporating the possible effects of freshwater inputs from melting land ice sheets (Greenland and Antarctica). IPCC (2001) conclude that it is too early to say whether and at what threshold irreversible shut-down of the Thermohaline circulation might occur. Results from nine GCMs indicate weakening but none show abrupt changes or complete breakdown in overturning in the Atlantic although Bigg et al. (2003) note that some studies suggest that breakdown could occur as a function of the magnitude and rate of greenhouse forcing.

2.3 Climate and fisheries

The majority of the world’s 200 million fisherfolk (fishers and other fishworkers) live in areas exposed to human-induced climate change, or depend for a major part of their livelihood on resources whose distribution and productivity are known to be influenced by climate variation. Despite this, there has not been a systematic global study of the likely impacts of climate change on the small-scale fisherfolk, often living in poverty, who use coastal and inland aquatic resources. Most studies of climate change and fisheries have focused on oceanic regime changes and the major pelagic fish stocks of upwelling zones that are the target of large scale industrial fisheries (reviewed in Klyashtorin, 2001). There exists, however, a scattered body of literature on the impacts of present day variability and observed climate change in small-scale fisheries (e.g. McClean and Tsyban, 2001 for IPCC; Sear et al., 2001, for the British Overseas Territories). This literature suggests that, in addition to the many demographic and economic pressures and governance failures that threaten the sustainability of fishery production systems, climate change is a significant factor contributing to uncertainty regarding the future of fisheries. Uncertainty undermines attempts to set long-term policy and management goals for fisheries, or to get fisherfolk to commit to local resource stewardship. Uncertainty linked to changing climate will therefore, at the very least, contribute to on-going difficulties in managing fisheries under uncertainty. Subsequent sections of this report will outline the many other ways in which climate change is likely to impact on the places where fisherfolk live, the infrastructure they utilise and the ecosystems they depend upon.

Resource-dependent communities in the developing world have adapted to climate variability throughout history. Studies of livelihoods in small-scale fisheries in both marine and inland waters (reviewed in Allison & Ellis, 2001) indicate that migration and livelihood diversification are key adaptive livelihood strategies in fisheries ranging from Arctic Canada to the Equatorial Pacific. But projected climate change poses multiple risks to fishery-dependent communities because of the increased frequency of extreme weather events, the potential for large-scale phase shifts, and from risks that lie outside the realm of present day experience (Adger et al., 2003). The multiple stresses associated with coastal urbanization, changes in the frequency and intensity of coastal storms and hurricanes, and the impacts of climate change on sensitive coastal ecosystems such as coral reefs and mangroves make this a key issue of concern for vulnerability and security of resource-dependent communities. Although coastal fisheries communities often have access to alternative income sources, they are likely to be squeezed out in the trends of increasing demographic pressures in coastal areas.

In inland fisheries, there is an emerging body of research suggesting that the dynamics of fisheries in Africa's lakes are driven primarily by climate change and that both the ecosystems and the livelihoods of fisherfolk living near these waterbodies are highly adapted to extensive fluctuations (e.g. Jul-Larsen et al., 2003). Recent research on Lake Tanganyika suggests that lake productivity decline, driven by changing regional climate, may be the primary reason for reduced fish catches (O'Reilly et al., 2003). In river basins, it has long been recognized that flow rates and the extent of flooding are strongly determinant of fish catch variations (Welcomme, 2001, for review). This research is shifting policy agendas from attempts to manage fisheries for maximum sustainable yields towards recognition of fisheries' role as either safety net or sporadic income-generating opportunity for occupationally and geographically mobile populations.

This research project will provide a synthesis of current thinking on the relations between climate change, vulnerability and adaptation and the design of appropriate response strategies. It will set out a research agenda in this field, based on identified gaps in current knowledge about impact and adaptation by coastal and riparian populations. This is a relatively new direction for the sector. Most research on climate change and fisheries to date has been targeted at understanding in detail the mechanisms *causing* fluctuation in fish stock size and distribution. This is the study of fish recruitment processes and the environmental factors driving them (e.g. Cushing, 1996). There has been much less emphasis on the study of the *responses* of fishers to stock size fluctuations, and even less on their capacity – or lack thereof – to respond. To understand these responses, we examine them in the context of evolving ideas on the relationships between risk exposure, sensitivity of livelihood systems, and the capacity to adapt to changes and shocks. These ideas are outlined in the next section.

2.4 Defining and measuring vulnerability to climate change

Planning effective adaptation to climate change and its associated risks requires robust and transferable methods of identifying who and what is vulnerable and the capacity of systems and social groups to cope with both climate variability and climate change. Some adaptation research has focused on decision-making frameworks that elaborate the economic costs or potential welfare outcomes of adaptation decisions (Fankhauser et al.1999; Adger et al., 2004). Much of this research is focused on adaptation decisions taken by governments or for other interventions. A prior question is the identification of where adaptation interventions should take place – i.e. those systems and communities at risk from climate change or other environmental stresses.

There are two main approaches to vulnerability analysis in the context of environmental change and climate change in particular. The first involves specific measurement of key parameters of vulnerability with a view to specified interventions, stemming from the work on food security and disaster reduction (reviewed in Downing 1992 and Downing et al., 2001). A second strand seeks broader indicators to create profiles of vulnerable situations or syndromes, spatial maps of vulnerability or national comparisons of vulnerability (Downing et al., 2001; Luers et al., 2003; Turner et al., 2003). Both of these approaches to vulnerability rely on underlying concepts of what constitutes vulnerability and both recognize that vulnerability is a state that cannot be directly observed – it is a relative concept underpinned by values of social and physical risk. It is the second of these two approaches that is adopted in this project.

The concepts which underpin vulnerability analysis are often contested and not clearly defined. In the context of climate change, the Intergovernmental Panel on Climate Change has developed working definitions of key terms and outlined the relationship between them:

> ***"Vulnerability is the extent to which climate change may damage or harm a system; it depends not only on a system's sensitivity, but also its ability to adapt to new climatic conditions"***
>
> (IPCC, 2001).

In the social realm vulnerability can be defined as the exposure of groups or individuals to stress as a result of climate variability and change. This definition emphasizes the social dimensions of vulnerability and follows the tradition of analysis of vulnerability to hazards and food insecurity as a dimension of entitlement to resources (see Adger and Vincent 2004). It complements notions of physical vulnerability to the impacts of natural hazards that concentrate on the physical dimensions of risk. Vulnerability is therefore made up of a number of components including exposure and sensitivity to hazard and the capacity to adapt:

$$\text{Vulnerability} = f(\text{exposure, sensitivity, adaptive capacity})$$

In IPCC terminology, **the degree to which the individual or social group will face a change in climate is their risk exposure.** This might be measured as the expected degree of temperature change, sea level rise, or increase in storm frequency they will face**. Sensitivity is the degree to which a system will respond to a change in climatic conditions**. This could be measured, for example by a proportional change in ecosystem productivity as a result of perturbations in temperature or precipitation. Sensitivity can also refer to the degree to which a society will be influenced by any such change. Under this latter definition, a country in which fisheries play are larger economic or nutritional role would be regarded as more sensitive to climate-fishery interactions than one in which fisheries only plays a minor part. **Adaptive capacity is the ability of a system to evolve in order to accommodate climate changes or to expand the range of variability with which it can cope** (e.g., Jones, 2001).

There are generic features of adaptive capacity of societies to all hazards and types of stress. Such inherent capacities are influenced by the **resources available to cope** with exposure, the **distribution of resources** across the landscape and among groups within a population, and the **institutions which mediate both resources and coping** with climate change and variability. Change in social vulnerability from its baseline level incorporates notions of economic development, as well as adjustments to livelihoods based on adaptation to hazard, and changes in institutional and political structures.

A key lesson from vulnerability analysis is the observation that the phenomenon is socially and spatially differentiated. In other words, climate change imposes heterogeneous burdens on different groups in society depending on their ability to cope. Many comparative studies have noted that the poor and marginalized have historically been most at risk from climatic shocks (Reardon and Taylor, 1996) even where societies have been, in aggregate, well adapted.

Adaptive capacity is a vector of resources and assets that represent the asset base from which adaptation actions and investments can be made. Within the IPCC Third Assessment Report, it is recognized that this capacity may be latent and be important only when sectors or systems are exposed to the actual or expected climate stimuli (Smit et al., 2001).

Vulnerability to climate change is therefore made up of a number of components including exposure to impacts, sensitivity, and the capacity to adapt. Adaptive capacity is, in this framework, a component of vulnerability. Adaptive capacity has diverse elements encompassing the capacity to modify exposure to risks associated with climate change, absorb and recover from losses stemming from climate impacts, and exploit new opportunities that arise in the process of adaptation.

Adaptation to climate change is the adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts. Adaptation involves changes in processes, practices and structures to moderate potential damages or to benefit from new opportunities. Adapting to variability in weather and climate is not in itself adaptation to climate change, although improving adaptations to variability can reduce vulnerability and hence build resilience for dealing with a changing climate.

Adaptation decisions taken by individuals (e.g. to use insurance, relocation away from threats, or changing technologies) and take place within an institutional context that can act to facilitate or constrain adaptation. It is clear that individuals and societies will adapt and have been adapting to climate change over the course of human history – climate is part of the wider geographical and historical landscape of human habitation and remains an important fact of life in resource dependent societies (Adger et al., 2003). Thus individuals and societies are vulnerable to climate risks and other factors and this vulnerability can act as a driver for adaptive resource management, of the kind already seen in many small-scale fisheries subject to climate-driven and other uncertainties (Allison & Ellis, 2001; Jul-Larson et al., 2003).

There are various geographic scales and social agents involved in adaptation. Some adaptation by individuals is undertaken in response to climate threats, often triggered by individual extreme events. Other adaptation is undertaken by governments on behalf of society, sometimes in anticipation of change but again, often in response to individual events. Government policies and individual adaptations are not independent of each other – they are embedded in governance processes that reflect the relationship between individuals, their capabilities and social capital, and the government.

One way of understanding peoples' existing adaptive responses and capacities is through the adoption of a livelihoods framework (e.g. Carney, 1999). The principles of the sustainable livelihoods approach (SLA) include an explicit recognition that development should 'build on strengths' – these strengths, in this context, are a measure of adaptive capacity. Thus, the SLA principles are relevant to consideration of responses that include building adaptive capacity of fisherfolk and governments to respond

It is these concepts of risk exposure (to climate change), sensitivity (of national economies to possible climate-induced changes in their fishery sectors) and capacity to adapt to change (in climate or other hazards) that are used in the analysis of vulnerability carried out under this project (see 4.3.1).

A note on climate change mitigation..

We do not, in this report, consider the issue of mitigation. Mitigation, in the context of the climate change literature, refers specifically to measures to reduce future climate change, for example through various means of reducing CO_2 emissions or increasing Carbon sequestration. The fisheries sector makes only minor contributions to global climate change (Troadec, 2000). The two ways in which the fisheries sector can contribute to climate change mitigation are:

- Reducing the use of fossil fuels (e.g. through promoting static gear use, rather than active gear, which requires larger engines and more fuel)
- Promoting the consumption of fresh, locally-caught fish with low 'food miles' – this reduces the amount of fossil fuel used to produce a given quantity of fish by reducing the need for transport and refrigeration or processing (e.g. canning).

While it is worth noting that these measures can make a small contribution to climate change mitigation, these are not their main purposes and benefits. Promoting use of static gear tends to favour smaller-scale operators and more species and size-selective fishing methods that have lower ecological impacts, thereby having broader fishery management benefits. Promoting the consumption of local foods is a broader social issue, where losses of livelihood and export opportunities for producers must be considered alongside any perceived environmental and social gains in 'shopping local'.

2.5 Summary and identification of demand

Understanding the impact of climate change and identifying possible means to reduce that impact on the poor, for example by building their adaptive capacity and the capacity of the institutions that serve them, has become a major theme in the environment and development field. The impacts of climate change on fishery production systems has been a long-standing concern in fisheries science, but this concern has not yet been explicitly linked to issues of poverty alleviation and vulnerability reduction among fishery dependent communities and in fishery-dependent regions. This project develops a framework for making those links and identifies research needed to better understand them.

The demand for the project was identified from three main sources:
I) The UK Department for International Development has identified Climate Change's impact on poverty as one its four major research themes[1], recognising that little existing research on climate change is focussed on poverty impacts (DFID, 2004, p10).

ii)The Fisheries Management Science Programme has undertaken several research projects that have highlighted the importance of climate-driven variations on the production dynamics of aquatic ecosystems and fish stocks, as well as undertaking research on coastal, lake and river floodplain livelihood systems that are affected by and respond to climate variability.

iii) The academic and policy literature on global climate change makes little mention of the fisheries sector. Climate variability and extreme events are known to have significant impacts on the sector, whose importance to poverty alleviation is often

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[1] The other three major DFID research themes are: sustainable agriculture (especially in Africa), killer diseases, and development in states that do not work for the poor.

under-appreciated. This project aims to help ensure that the fisheries sector is not overlooked in climate change impact studies and attempts to reduce impact. Widespread concern exists on the vulnerability of coastal livelihood systems to climate change. This is evident in the work of the IPCC and the coastal/wetland/water resource focus of many rural development programmes and projects funded by donors, governments and NGOs.

Recent work has introduced the concept of vulnerability assessment and sustainable livelihoods (VASL) of the rural poor in the context of climate change (see Ziervogel and Calder, 2003) but there is no significant work to date focusing on small-scale fisheries in low-income countries. Given the already widespread concern over fisheries sustainability (as evidenced by the Johannesburg Declaration on Responsible Fisheries) and increasing awareness of the important contributions of fisheries to the regional and national economies of some of the world's poorest countries, this represents a significant knowledge gap.

The forecast of the impact of climate change on poor fisherfolk will allow adaptation strategies to be designed, thereby increasing livelihood security and reducing the need for short-term coping strategies that increase vulnerability, such as the sale of productive assets.

3 PROJECT PURPOSE

The purpose of the project was to review existing information relevant to the potential impact of climate change on the sustainability of capture and enhancement fisheries important to poor people. The project report provides a synthesis of current thinking on the relations between climate change, vulnerability and adaptation strategies of poor fisherfolk. It also provides an analytical framework within which to consider issues of vulnerability.

The project is an FMSP programme development activity. Its aim is to identify researchable constraints to improved support for sustainable livelihoods of fisherfolk currently living in poverty and vulnerable to future climate change. The objective of the research is to propose the incorporation of these identified researchable constraints in future programme planning relevant to the fisheries sector in developing countries.

Thus, the focus is on identifying a research agenda, not on proposing a series of development actions. The starting point for the project is the premise that, although there are a number of known strategies to help reduce vulnerability of the poor to climate change, not enough is yet known to allow a programme of intervention to be specifically targeted to support fisherfolk. The research proposed as an output of this project aims to develop the required knowledge base alongside on-going actions.

4 RESEARCH ACTIVITIES

This report is based on the review, synthesis and analysis of secondary data, and aims to present the state of knowledge about the likely impacts of future climate change on the livelihoods of fisherfolk living in poverty. The research was undertaken between April and October 2004. The sequential research process undertaken can be summarised as follows:

4.1 Literature review

A review of literature was conducted and relevant papers, data-sources, books and reports were collated under the following subject categories:

1. Climate change and climate variability assessments and forecasts, with emphasis on changes evident in aquatic systems
2. Links between climate and biophysical processes affecting fish stock productivity and distribution and aquatic ecosystems
3. Impacts of climate variability and change on coastal and riparian environments and livelihood systems, with emphasis on fisherfolk
4. Case study analyses on vulnerability, poverty and resource dependency in coastal and riparian communities, with emphasis on fisherfolk
5. Methodologies for climate change vulnerability assessment, with emphasis on LDCs
6. Methodologies and case-study experience in addressing the impacts of climate change, with emphasis on LDCs

4.2 Identification of mechanisms through which climate change may influence fisheries

The literature review was used to identify the range of mechanisms through which climate change may influence fisheries. A synthesis of identified pathways of influence was prepared, for use in future research activities. The synthesis was based primarily on observed historical climatic and environmental impacts on aquatic ecosystems, species, and fisheries, but also incorporated predictions about how systems are likely to respond to future climate change. For simplicity, mechanisms were categorised according to broad issues, and impacts were identified at different ecosystem levels (environment or habitat, phytoplankton and zooplankton, and fish or invertebrates). Main and resultant effects were noted where possible, but were not always clearly distinguishable, due to the fact that climatic effects are experienced simultaneously across trophic levels, and because most studies typically examine impacts on a single trophic level.

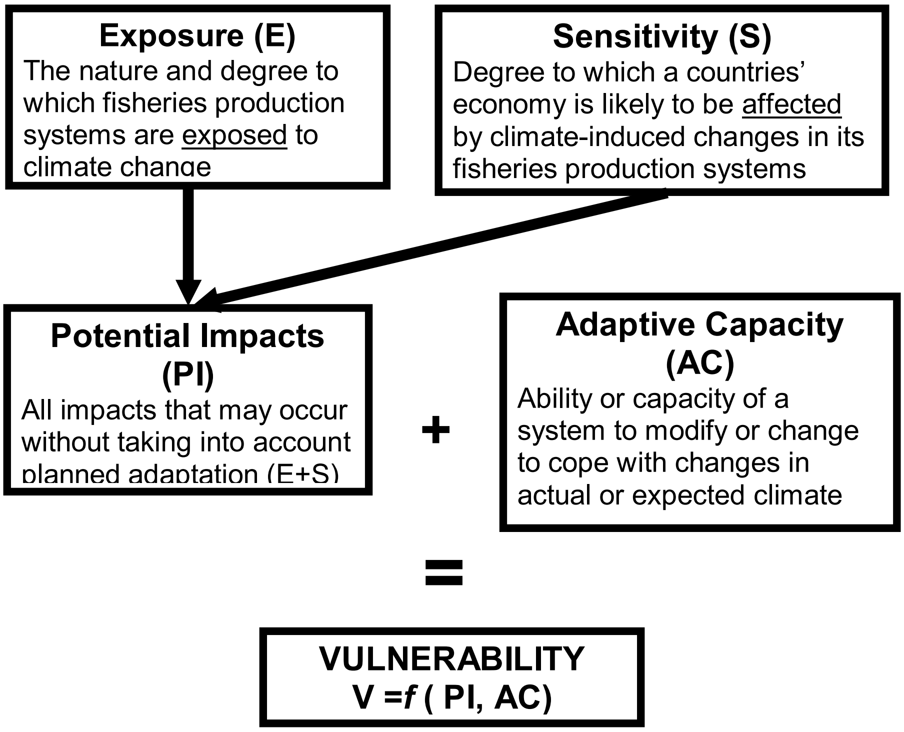
As well as the effects of climate change on the ecology of fish stocks, we also identified pathways through which climate change may impact on fishing operations and on the lives and livelihoods of people engaged in fishing activities. In this context, the literature on the impacts of past climate fluctuations and extreme events on fishing livelihoods and fishing operations provided the most useful data analogues to the potential impacts of future change.

4.3 Mapping climate change vulnerability at global level

4.3.1 Conceptual Framework

The IPCC definitions of vulnerability to climate change were used in this study (McCarthy *et al.*, 2001). Figure 4.1 presents the definition of some of the fundamental terms used.

Figure 4.1 Conceptual model for assessment of vulnerability of poor fisherfolk to climate change



Potential impacts of climate change are a function of exposure (E) to climate change and sensitivity (S) of the economic, production or livelihood systems under consideration to the changes to which they are exposed:

$PI = f(E, S)$

Vulnerability is a function of the potential impacts of climate change, reduced or modified by peoples' or institutions' adaptive capacity:

$V = f(PI, AC)$

This approach in terms of definition of vulnerability is similar to that used in other recent vulnerability studies in other sectors (Metzger *et al.*, 2005; O'Brien *et al.*, 2004; Schröter *et al.*, 2004)

4.3.2 Identification of indicators

For each component of vulnerability a set of indicators was assigned, as presented in Table 4.1. Indicators of exposure and adaptive capacity were chosen based on past vulnerability studies and relevant literature. The choice of sensitivity indicators was more subjective and based on our expert judgement, no study specifically addressing the sensitivity of the fishery sector to climate change being available.

Table 4.1 Summary of indicators and variables used in their construction

Component	Indicators	Variable
Exposure (E)	Temperature (^{o}C)	Modelled temperature change for 2050
Sensitivity (S)	Index of Poorest fisherfolk	Number of fisherfolk GDP/Capita
	Index of Economic Dependency on the Fisheries sector	Fisheries exports as % of total exports (export dependency) % of economically active population involved in the fishery sector (reliance on employment)) Total catch in tons (reliance on stocks)
	Index of Nutritional Dependency	Fish protein as % of all animal protein (per capita per day in g)
Adaptive Capacity (AC)	Health	Healthy Life Expectancy
	Education	Literacy rates School enrolments ratios
	Governance	Political stability Government effectiveness Regulatory Quality Rule of law Voice and accountability Corruption
	Size of Economy	Total GPD

In this analysis, an important modification is made to the concept of sensitivity. Usually, sensitivity would be taken as the biophysical and socio-economic response of the fishery sector to climate change exposure. However, because of the multitude of pathways by which climate change exposure may affect fishery production systems (see Section 5.2) and because of the difficulty of the current impossibility of parameterising any sensitivity indicators for the sector, we considered it more useful to consider sensitivity in a slightly different context - that in which a countries' national economy was likely to be sensitive to any climate-induced impacts on its fisheries sector. Thus, countries with larger fishery sectors, greater employment and nutritional contribution of fisheries were regarded as being more 'sensitive' than countries with insignificant fisheries, to any given level of exposure to climate change.

In our analysis of fisheries production systems' sensitivity, we have identified food security, economic dependency and the location of the highest number of poor fisherfolk as the major indicators of a countries' sensitivity to climate-change impact in relation to fisheries. It is estimated that between 15 and 20 percent of all animal protein comes from aquatic animals, and of the 30 countries most dependent on fish as a protein source, all but four are in the developing world (FAO, undated). Increased stress on food production systems such as fisheries, driven by climate change, could thus have significant repercussion on food security. Countries that are more economically dependent on the fisheries sector (i.e. in terms of employment and exports) are more likely to be impacted (positively or negatively) by changes in fishery production due to climate change. Finally, it is important to identify areas where a high number of poor fishing communities are located in order to direct aid and assistance according to DFID/FSMP priorities regarding poverty reduction. Thus, these indicators on 'sensitivity' are indicators of the likely importance or significance of any climate-induced changes to the national economy (i.e. the sensitivity of the economy to fishery-related changes)

4.3.3 Spatial and temporal scale

We use the IPCC typology to develop a vulnerability assessment not at the sub-national (O'Brien et al, 2004) or regional level (Metzger et al 2004), but at the national scale. Despite the fact that vulnerability is highly context specific, rarely unfolding at the level of a nation state, making the use of national level indicators not always appropriate, the wider availability of the data at this scale is a major factor in its choice. Sub-national vulnerability is also often influenced by processes operating at the national scale (Adger et al, 2004).

We aimed to include as many countries and regions as possible in our analyses. However, due to the additive nature of our analyses, vulnerability could not be assessed where data required for calculating values for component indices were not available. For exposure data, missing values were interpolated where this seemed sensible (typically in the case of small islands), and average values were calculated for several island groups where sensitivity and adaptive capacity data were reported at a coarser spatial scale.

The aim of our vulnerability assessment was to capture a snapshot of *present-day* vulnerability of fisheries production systems to future climate changes. Thus data for the sensitivity and adaptive capacity components represent current socio-economic conditions of the system studied, while exposure is based on predicted temperature changes. Recently, a database has been developed containing downscaled socio-economic scenarios of future population and GDP at the country level and on a geo-referenced gridscale (Gaffin et al., 2004), giving scope for studies on future pattern of vulnerability. However, some scholars argue that current vulnerability is still the best proxy – reducing uncertainty pertaining to indicators - and is appropriate for identifying means of increasing adaptive capacity (Adger and Kelly, 1999 cited in Adger and Vincent, 2004).

4.3.4 Construction of indices and indicators

Each indicator has associated with it a number of variables that are empirically measured. The choice of variables, similar to that in construction of other indicators such as the Human Development Index (HDI) or the Sustainable Development Index developed by the Stockholm Environment Institute (SEI), was driven by a consideration of a number of factors including: country coverage, how recent the data was, the direct relevance to the phenomenon that the indicators are intended to measure, and quality of the data (SEI Report, 2002). Missing data in the construction of indicators are an endemic problem. Details on data sources and more detailed discussion of methods used to obtain values for all the variables are given in Annex 1.

Variables were normalised using the indexing method, following the general formula:

> Index value = (actual value – minimum value)* 100 / (maximum value – minimum value)

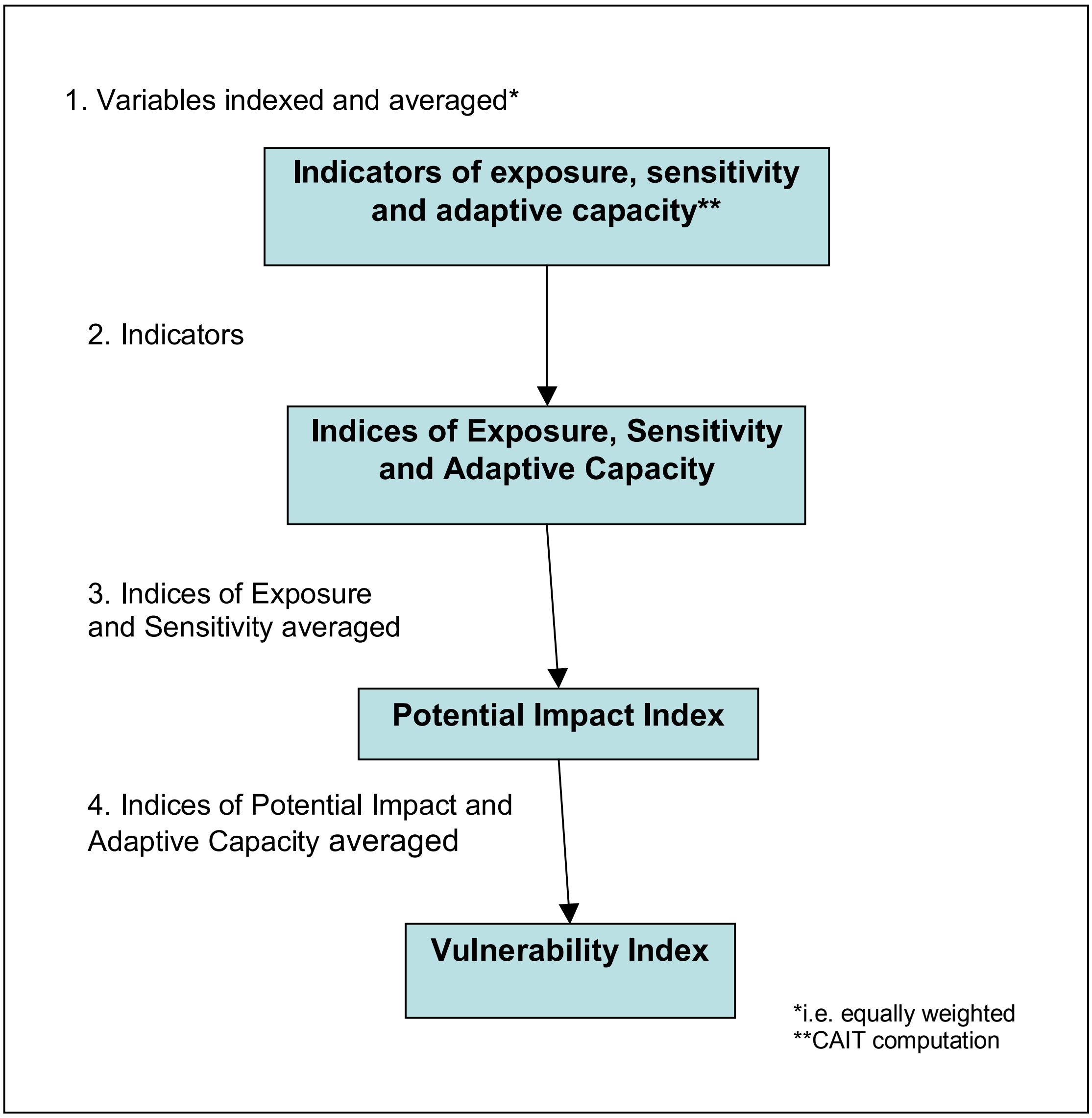
In cases when the indicators were made up of several variables, index values were calculated as above for each variable and the index values were simply averaged to obtain the indicators. Thus, the 17 variables given in Table 4.1 were reduced to eight indicators. Indexing allows us to represent the distribution of each indicator on a common scale, which can facilitate comparisons. For our purposes, indicators are indexed to a scale of 0 to 100, where 0 represents the minimum value and 100 represents the maximum value.

For the adaptive capacity index we did not manipulate the raw data; it was directly computed by the Climate Analysis Indicator Tool (CAIT) of the World Resource Institute. The CAIT uses a similar methodology to ours. For further information, see the *Indicator Framework Paper* (http://cait.wri.org/downloads/framework_paper.pdf).

Figure 4.2 (overleaf) summarises the different steps in the construction of the vulnerability index. Further details on the sources of data and calculation of country values for each variable are given in Annex 1.

In this analysis, risk exposure is calculated from a single variable (surface air temperature), while sensitivity is calculated from a range of variables. Risk exposure and sensitivity measures were then averaged to produce an indicator of potential impact of climate change. This was then added to the adaptive capacity indicator, and the resulting vulnerability. Thus, adaptive capacity is weighted equally with the potential impact – the combination of risk exposure and sensitivity. This may unduly emphasise adaptive capacity, and it may be that averaging risk exposure, sensitivity and adaptive capacity alters the ranking of vulnerability produced here. We are currently conducting analyses of the sensitivity of the conclusions to different averaging and weighting procedures.

Figure 4.2 The four steps in the construction of the vulnerability index. Shaded boxes represent the result of each computational step.



4.3.5. Climate Change Scenarios

The exposure index aims to represent the degree to which fisheries production systems are exposed to climate change. Climatic change influences fisheries production directly (e.g. through effects on species abundance and distribution), and less directly (e.g. through impacts on aquatic habitats, food supply, competitors, and predators) and through various pathways that also include impacts on fisheries-related infrastructure or operations (increased storminess, changing coastlines) and on other aspects of fisherfolks' lives (e.g. changing prevalence of infectious disease agents, flood damage to peoples' property etc). The climate variables that cause these impacts include changes in temperature, precipitation, salinity, ocean circulation and mixing, river flow, nutrient levels, sea and lake levels, ice cover, storm frequency and intensity, and flooding. Predicted changes in these climate parameters are all, however, related to the phenomenum of global warming. Temperature is both the most straightforward measure of climate change, and the best understood. We therefore used projected temperature change as a general proxy variable of climate change exposure.

Temperature change in degrees Centigrade (at 1.5 m above the surface) for 2050 were taken from the Tyndall Centre's TYN CY 3.0 dataset compiled by Mitchell et al. (2003). The projections we used were based on two different SRES climate change scenarios, A1FI and B2. These scenarios were selected because they describe two contrasting potential futures; the A1FI world is characterised by a high dependency on fossil fuels, reflected in higher temperatures than in the B2 world, in which economic development is more moderate (see Box 4.1, overleaf). Country-specific values were derived by Mitchell et al. (2003), based on gridded values from the Hadley Centre's HadCM3 climate model outputs. Changes in annual mean temperature for 2050 were estimated by applying scalers from Mitchell et al. (2003) to temperature anomalies for 2080 (2071-2100, as compared to 1961-90). Where possible, values for countries missing from the TYN CY 3.0 dataset were interpolated based on the nearest available regions. Values for two island groups (French Polynesia and the French Southern Territories) were calculated by averaging values from individual islands that were reported separately.

Box 4.1 A summary of the four main scenarios in the Special Report on Emissions Scenarios (SRES), published by the Intergovernmental Panel on Climate Change (IPCC, 2001)

A1
A future world of very rapid and successful economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. There is a strong focus on education, technology, and institutions at the national and international levels, and the majority of people experience a great improvement in their overall health and social conditions. Rapid technical progress “frees” natural resources currently devoted to provision of human needs for other purposes, and the current emphasis on “conservation” of nature shifts toward active “management” of natural and environmental services, which increases ecologic resilience.

The A1 scenario family consists of four scenario groups that describe alternative directions of technological change in the energy system, varying from carbon-intensive to decarbonization paths. Emissions within the A1 scenario family are therefore highly variable. We have focused here on A1FI, a fossil fuel-intensive scenario.

A2
A very heterogeneous world, with underlying themes of self-reliance and preservation of local identities. An emphasis on family and community life results in the very slow convergence of fertility rates across regions, and A2 population growth is the highest among the storylines. Economic development is mainly regionally focused, and economic growth and technological change are more fragmented and slower than in other storylines. Global average per capita income is low, and international disparities in income per capita, are largely maintained or increased in absolute terms. Economic, social, and cultural interactions among regions are less important, and technological diffusion is slow. Technological change is globally heterogeneous; some regions evolve more resource-intensive economies, while those poor in resources emphasise technological innovation to improve resource efficiency. Attention is given to potential local and regional environmental damage, but this varies across regions, and environmental concerns are relatively weak at the global level.

B1
A convergent world with low population growth, rapid changes toward a service and information economy, ‘dematerialization’, and a relatively smooth transition to clean and resource-efficient technologies. Levels of environmental and social consciousness are high, and the emphasis is on global solutions to economic, social, and environmental sustainability. Economic development is balanced, and significant progress is made toward international and national income equality. Most potentially negative environmental aspects of rapid development are anticipated and effectively dealt with locally, nationally, and internationally. Technological change, as well as proactive local and regional environmental measures and policies, lead to relatively low greenhouse gas emissions, even in the absence of explicit climate change policies.

B2
A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. This world is characterised by moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change. The scenario is also oriented toward environmental protection and social equity, but focuses on local and regional levels, with a trend toward local self-reliance and stronger communities. International institutions decline in importance, in favour of a shift toward local and regional decision-making structures and institutions. Human welfare, equality, and environmental protection all have high priority, and they are addressed through community-based social solutions in addition to technical solutions.

4.4. Case studies of the impacts of climate change on vulnerability of fisherfolk living in poverty

Global vulnerability mapping is useful for highlighting countries and regions where the impact of climate change on fisheries and poverty are likely to be significant. But because the mechanisms by which climate change may impact on fishing-based livelihoods are complex and various, it is not possible to posit an overall relationship between climate change, poverty and fisheries that will be operationally useful at programme level. In order to understand in more detail, therefore, how climate, fisheries, poverty, vulnerability and possible adaptation of mitigation strategies can be linked, we consider the impact on particular fisheries, ecosystems or ecoregions and their dependent populations. These case studies are intended to illustrate the type of research that could help to inform the design of suitable country or ecosystem-level policy and programme intervention to develop adaptive capacity of fisherfolk to deal with future climate change, and to support mitigation strategies for existing and anticipated impacts. They are not intended to be representative of importance of particular fishery types, but give an illustration of the type of work that is being done in this field. They are summarised from the experience of particular project participants (Dulvy, Coral Reefs; Allison & Conway, African Lakes; Halls, Bangladesh floodplain fisheries) and builds on previous projects conducted under the Fisheries Management Science Programme[2]

4.4.1 Coral reefs

The aim of this case-study was to develop demographic and ecological statistical models to describe the link between the per capita fish consumption of fisherfolk and the potential supply and demand of reef resources at national scales, under different scenarios of population growth and climate change impacts, taken as temperature-change induced losses of coral cover due to coral bleaching. The approach was to compile national level statistics and use each nation as a datum in a comparative analysis. Details of the methodology are given in section 5.4.1 along with the results, interpretation and implications of the analysis.

4.4.2 African Lakes

The aim of this case-study was to use recent published analyses of past and predicted climate change, included projected change in precipitation variability and levels, and their observed and projected impacts on lake levels and lake productivity, together with documented analysis of livelihood and institutional responses to past climate change and variability, to identify existing adaptive strategies and assess how they might be built upon. The analysis is centered on the Eastern/Southern part of the continent and concentrates on Lakes Chilwa and Tanganyika, as examples of productive shallow wetlands and deeper rift-valley lakes, respectively. The overview is presented in Section 5.4.3.

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[2] Recent FMSP projects of relevance are: R7040 (Strategic Review of Tropical Fisheries Management); R7041 (Software for estimating potential yield under uncertainty); R7336 (Sustainable Livelihoods from Fluctuating Fisheries); R8118 (Understanding Livelihoods dependent on inland fisheries in Bangladesh and South East Asia); R8196 (Understanding fisheries livelihoods and constraints to their development:: Kenya and Tanzania);

4.4.3 River basins and floodplains – Bangladesh case study

The aim of this case study was to use a simulation model that links river flow rates and flooding with floodplain fish production to explore the likely impacts of climate change (and climate change responses such as increased flood control) on the important floodplain fisheries of Bangladesh and their dependent livelihoods. The model, its application and interpretation of its conclusions in the light of projected climate-change scenarios for Bangladesh are presented in Section 5.4.3.

4.5 Identification of knowledge gaps and proposed research agenda

Based on the research activities outlined above, we identified knowledge gaps needed to improve targeting of activities to reduce risk exposure and sensitivity to climate change, and to build adaptive capacity, so that the poorest countries with important fisheries sectors can begin to build appropriate responses to reduce the vulnerability of their fisherfolk and the people and economic sectors they interact with. We have suggested research needs to fill the identified gaps in our knowledge.

5 OUTPUTS

5.1. Literature review

A detailed literature review was collated as part of this research programme. It is being checked and made available to other researchers with the support of a follow-up project (R8475) that aims to disseminate the findings of this study and other previous climate-change related research conducted under the fisheries management science programme. As a starting point for others beginning research in this field we present in Box 5.1 some of the key recent literature in the field of climate change and fisheries.

Box 5.1 Some key literature relevant to linking climate variability with fisheries production systems, the vulnerability of fisherfolk to future climate change, and possible responses to climate change

1. Climate change and climate variability assessments and forecasts, with emphasis on changes evident in aquatic systems

Bakun A. (1990) Global climate change and intensification of coastal ocean upwelling. *Science* 247: 198-201.

Carpenter S. R., Fisher S. G., Grimm N. B. & Kitchell J. F. (1992) Global Change and Fresh-Water Ecosystems. *Annual Review of Ecology and Systematics* **23**: 119-139.

Levitus S., Antonov J. I., Boyer T. P. & Stephens C. (2000) Warming of the world ocean. *Science* **287**: 2225-2229.

Nicholls R. J., Hoozemans F. M. J. & Marchand M. (1999) Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environmental Change - Human and Policy Dimensions* **9**: S69-S87.

Timmermann A., Oberhuber J., Bacher A., Esch M., Latif M. & Roeckner E. (1999) Increased El Niño frequency in a climate model forced by future greenhouse warming. *Nature* 398: 694-697.

Watson R. T. & and Core Writing Team eds. (2001) *Third Assessment Report of the Intergovernmental Panel on Climate Change. Climate Change 2001: Synthesis Report*. Cambridge University Press, Cambridge, UK.

2. Links between climate and biophysical processes affecting fish and invertebrate stock productivity and distribution and aquatic ecosystems.

Glantz M. H. ed. (1992) *Climate variability, climate change, and fisheries*. Cambridge University Press, Cambridge.

Klyashtorin L. B. (2001) Climate change and long term fluctuations of commercial catches: the possibility of forecasting. *FAO Fisheries Technical Paper* **410**, 86 pp. FAO, Rome.

McLean R. F., Tsyban A., with Burkett V., Codignotto J. O., Forbes D. L., Mimura N., Beamish R. J. & Ittekot V. (2001) Coastal Zones and Marine Ecosystems. In: *Third Assessment Report of the Intergovernmental Panel on Climate Change. Climate Change 2001: Impacts, Adaptation and Vulnerability* (eds. J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken & K. S. White) pp. 343-379. Cambridge University Press, Cambridge, UK.

McGinn N. A. ed. (2002) *Fisheries in a Changing Climate*. American Fisheries Society, Bethesda, Maryland.

Wood C. M. & McDonald D. G. eds. (1997) *Global Warming: Implications for freshwater and marine fish*. Cambridge University Press, Cambridge.

3. Impacts of climate variability and change on coastal and riparian environments and livelihood systems, with emphasis on fisherfolk

Aaheim, H.A. & Sygna, L. (2000). *Economic impacts of Climate Change on Tuna Fisheries in Fiji Islands and Kiribati*, CICERO Reports. 2000:04, Center for International Climate and Environmental Research, University of Oslo, Oslo.

Field C. D. (1995) Impact of Expected Climate-Change on Mangroves. *Hydrobiologia* **295**: 75-81.

Hoegh-Guldberg O. (1999) Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research* **50**: 839-866.

Jul-Larsen, E., Kolding, J., Overå, R., Nielsen, J.R. and van Zwieten, P.A.M. (2003) 'Management, co-management or no management? Major dilemmas in southern African freshwater fisheries', 1. Synthesis, *FAO Fisheries Technical Report* **426/1**, Rome: FAO

Wilkinson C., Linden O., Cesar H., Hodgson G., Rubens J. & Strong A. E. (1999) Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and a warning of future change? *Ambio* **28**: 188-196.

Zhang C. I., Lee J. B., Kim S. & Oh J. H. (2000) Climatic regime shifts and their impacts on marine ecosystem and fisheries resources in Korean waters. *Progress in Oceanography* **47**: 171-190.

4. Case study analyses on vulnerability, poverty and resource dependency in coastal and riparian communities, with emphasis on fisherfolk

Adger, N.W. (1999). Social Vulnerability to Climate Change and Extremes in Coastal Vietnam. *World Development*, **27**, 249-69.

Béné, C., Macfadayen, G. and Allison, E.H. (2005) Enhancing the contribution of small-scale fisheries to poverty alleviation and food security. *Fisheries Technical Report*, FAO, Rome. (*in press*)

Craig, J.F., Halls, A.S., Barr, J., & Bean, C.W. (2004). The Bangladesh Floodplain Fisheries *Fisheries Research* **66**: 271-286.

Jallow, B.P., Toure, S., Barrow, M.M.K., & Mathieu, A.A. (1999). Coastal zone of The Gambia and the Abidjan region in Côte d'Ivoire: sea level rise vulnerability, response strategies, and adaptation options. *Climate Research*, **12**, 129-136.

Morris, S., Neidecker-Gonzales, O., Carletto, C., Munguia, M., & Wood, Q. (2002). Hurricane Mitch and the livelihoods of the rural poor in Honduras. *World Development*, **30**, 49-60.

Neiland, A.E. and Béné, C., editors, (2004). *Poverty and Small-Scale Fisheries in West Africa.* Kluwer and FAO, Dordrecht, Netherlands and Rome, Italy.

Whittingham, E., Campbell, J., & Townsley, P. (2003). Poverty and reefs. DFID-IMM-IOC/UNESCO, Exeter, UK.

5. Methodologies for climate change vulnerability assessment, with emphasis on LDCs

Brody M. & Hlohowskyj I. (1998) Fisheries. In: *Handbook on Methods of Climate Change Impact Assessment and Adaptation Strategies* (eds. J. F. Feenstra, I. Burton, J. B. Smith & R. S. J. Tol) pp. 14.11-14.37. United Nations Environment Programme, Nairobi & Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

Eide, A. & Heen, K. (2002). Economic impacts of global warming: A study of the fishing industry in North Norway. *Fisheries Research*, **56**: 261-274.

Fankhauser, S., Smith, J. B. and Tol, R. S. J. (1999) Weathering climate change: some simple rules to guide adaptation decisions. *Ecological Economics* **30**: 67-78.

Jones, R. N. (2001) An environmental risk assessment/management framework for climate change impact assessments. *Natural Hazards* **23**: 197-230.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., & West, J. (2004). Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change* **14**: 303-313.

6. Methodologies and case-study experience in addressing the impacts of climate change, with emphasis on LDCs

Adger, W.N. (2003) Social capital, collective action and adaptation to climate change. Economic Geography 79(4): 387-404.

Aiken, K.A., Bacon, P.R., & Mooyoung, R. (1992). Recovery after Hurricane Gilbert: implications for disaster preparedness in the fishing industry in Jamaica. *Proceedings of the Gulf and Caribbean Fisheries Institute* **41:** 261-283.

Hansen L. J., Biringer J. L. & Hoffman J. R. eds. (2003) *Buying time: A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems*. WWF, Berlin, Germany.

Adger, W. N., Huq, S., Brown, K., Conway, D. & Hulme, M. (2002). Adaptation to climate change in the developing world. *Progress in Development Studies* **3**(3): 179-195.

SEI, IUCN, IISD, & Intercooperation (2003). *Livelihoods and climate change: combining disaster risk reduction, natural resource management and cliamet change adaptation in a new approach to the reduction of vulnerability and poverty*. Stockholm Environment Institute, IUCN, IISD, Intercooperation, http://iisd.org/publications/publication.asp?pno=529. 10/05/04.

Huq, S. Karim, Z., Asaduzzaman, M., & Mahtab, F. (1999). Vulnerability and Adaptation to Climate Change for Bangladesh. Kluwer Academic Publishers, The Netherlands.

5.2 Summary of mechanisms through which climate change may influence fish stocks, fisheries and fishing-based livelihoods

5.2.1 Links between climate change and biological responses of fish stocks and aquatic ecosystems

Mechanisms through which climate change may influence fisheries are synthesised in Table 5.1. Pathways of climate change effects are organised according to broad themes. Within each theme, key climate change variables are indicated, as well as those ecosystems for which effects have been noted and/or are predicted. Impacts within ecosystems are reported according to trophic level, with italics used to indicate effects that clearly result from changes at other trophic levels. The table should be read cautiously with respect to directions of change; where a specific change is indicated, this may reflect effects which are specific to a particular system, rather than a general expectation. Similarly, the absence of noted impacts indicates that none have been reported or predicted, rather than suggesting that no effects occur.

Note: Within the table, the following acronyms are used with respect to large-scale patterns of climatic variability: ENSO (El Niño/Southern Oscillation), NAO (North Atlantic Oscillation), PDO (Pacific Decadal Oscillation), SOI (Southern Oscillation Index), TPI (Trans Polar Index), ALPI (Aleutian Low Pressure Index), and ACI (Atmospheric Circulation Index).

Table 5.1 Summary of potential pathways for climate change impacts on fish stocks and aquatic ecosystems

Issue	Climate change variable	Ecosystem	*Impacts on:*			Example references
			Environment/ habitat	Phytoplankton/ Zooplankton	Fish/ Invertebrates	
Phenology (timing of natural phenomena)	warming, large-scale climatic variation	freshwater (temperate) marine (temperate)	• earlier ice retreat	• altered timing of peak abundance • altered timing of phytoplankton bloom & zooplankton abundance	• altered timing of spawning • altered timing of migration • altered timing of peak abundance • *better recruitment & survival*	Ahas 1999 ; Edwards & Richadson 2004; Ellison 2003; Hunt et al. 2002; Mackas et al. 1998; Sims et al. 2001
		marine – mangrove (tropical)	• altered phenology			
MIgratory patterns	warming	marine (temperate)			• shifts in migratory patterns according to prey abundance • shifts in species transport patterns with changes in surface winds, currents	Cushing 1982; Polovina 1996; Sharp 2003
	increased monsoonal winds	marine (tropical)	• *near-shore anoxia*	• increased algal growth	• *forced migration into estuaries*	
Occurrence of disease & harmful algal blooms (HABs)	warming	freshwater & marine (temperate)	• increased number & extent of HABs – *blocking light, depleting oxygen*	• *reduced primary productivity*	• *increased mortality*	Hallegraeff 1993; Harvell *et al.* 1999; Kim & Powell 1998; McLean & Tsyban 2001; Mudie *et al.* 2002; PAHO 2003; Roemmich & McGowan 1995; Tyedmers & Ward 2001
		freshwater – rivers (temperate)			• increased frequency of disease outbreaks & higher mortality risks for migratory species	
		marine – (temperate) & coral reefs (tropical)	• opportunistic diseases affecting temperature-stressed reefs		• increased disease susceptibility, increased disease exposure due to range expansion of pathogens	
	large-scale climatic variation (ENSO)	marine (temperate)			• correlation with infection intensity	
	increased precipitation	marine – coral reefs (tropical)	• decreased salinity & increased temperature with heavy river flow		• *increased mortality from freshwater-associated diseases*	
Sex ratios	warming	marine (temperate)			• skewed sex ratios in some species with temperature-dependent sex ratios	Conover 1984; Pavlidis *et al.* 2000
Invasive species	warming	freshwater & marine			• increased severity of problems with invasive species	Gitay *et al.* 2001; Hoffman 2003; Mandrak 1989

Issue	Climate change variable	Ecosystem	*Impacts on:*			Example references
			Environment/ habitat	Phytoplankton/ Zooplankton	Fish/ Invertebrates	
UV-B exposure	decreased precipitation/ drier conditions	freshwater – lakes & rivers (temperate)	• decreased input of dissolved organic carbon, so increased water clarity	• *increased UV-B exposure & damage*	• *increased UV-B exposure & damage*	Schindler *et al.* 1996; Yan *et al.* 1996
Behaviour	warming				• behavioural responses (e.g. changes in feeding & habitat selection)	Wood & McDonald 1997
Physiology	warming	freshwater & marine (temperate)			• increased metabolic demands & energetic costs, with reduced growth where limited access to prey • impacts on growth & survival (positive or negative depending on population & species) • impacts on reproductive maturation • effects on egg quality	Beaugrand *et al.* 2003; Bogstad & Gjøsæter 1994; Feely *et al.* 2004; Henderson *et al.* 1992; Hinch *et al.* 1995; Jobling *et al.* 1995; Mackenzie & Köster 2004; Magnuson *et al.* 1990;McDonald *et al.* 1996; Otterlei *et al.* 1999; Tyedmers & Ward 2001
	warming & increased atmospheric CO_2	marine			• potential for shell dissolution in calcifying (shell-building) species	
Recruitment	warming, large-scale climatic variation (e.g. ENSO)	marine			• impacts on recruitment levels (positive or negative depending on population & species)	Cushing 1982; Jacobson & MacCall, 1995; Lluch-Belda *et al.*, 1991; O'Brien *et al.* 2000; Ottersen *et al.* 2001; Planque & Fredou 1999
Distribution & range shifts	warming, changes in salinity, changes in ocean currents, large-scale climatic variation (e.g. ENSO, NAO)	freshwater & marine		• range shifts with warming, with changes in community composition	• range shifts with warming, with changes in community composition, & potential extirpations where dispersal rates slower than habitat change	Beaugrand *et al.* 2002; Bellido *et al.* 2001; Brody & Hlohowskyj 1998; Corten & van de Kamp 1996;Cushing 1982; Done 2003; Ellison 2003; Field *et al.* 1999; Fromentin & Planque 1996; Genner *et al.* 2004; Gitay *et al.* 2001; Holbrook *et al.* 1997; Kimura *et al.* 1999; Lehodey *et al.* 1997; Muraswki 1993; Sagarin *et al.* 1999; Shuter & Post 1990; Southward *et al.* 1995
		marine	• changes in location of major upwelling zones • changes in location of ocean fronts (e.g. salinity fronts)		• *impacts on distribution* • *impacts on recruitment where shifts in relative positions of spawning grounds, transport currents, & nursery grounds (fish)*	
		marine (tropical)	• coral reefs & mangroves may expand into higher latitudes			

Issue	Climate change variable	Ecosystem	*Impacts on:*			Example references
			Environment/ habitat	Phytoplankton/ Zooplankton	Fish/ Invertebrates	
Habitat availability	changes in precipitation	freshwater – lakes, swamp forest	• areas may dry, become isolated or merge, flood or erode		• *impacts on key stages of life cycle (e.g. spawning)*	Alleng 1998 ; Bird 1993 ; Bootsma & Hecky 1993 ;Brody & Hlohowskyj 1998; Brown & Suharsono 1990 ; Brown *et al.* 2000 ; Carpenter *et al.* 1992 ; Ellison & Farnsworth 1997 ; Ellison & Stoddart 1991 ; Ellison 2003 ; Field 1995 ; Hoegh-Guldberg 1999 ; Kjerfve *et al.* 1994 ; Kleypas *et al.* 1999 ; Lindahl *et al.* 2001 ; Marsh *et al.* 1986; Nicholls *et al.* 1999 ; Richmond *et al.* 1997 ; Schlager 1999 ; Short & Neckles 1999 ; Smith & Buddemeier 1992 ; Souter & Linden 2000 ; Spalding & Jarvis 2002 ; Turner 1977 ; Tyedmers & Ward 2001 ; Watson *et al.* 2001; Wilkinson 1999 ; Wilkinson 2002
	sea level rise	marine – coastal wetlands (e.g. mangroves, intertidal areas) & estuaries (temperate & tropical)	• habitat loss (where inland retreat not possible & 'coastal squeeze' occurs), sediment erosion, increased salinity		• *reduced recruitment & abundance for species dependent on wetland nursery grounds, & reduced fisheries yields*	
	warming, large-scale climatic variation (ENSO), increased CO_2, sea level rise	marine – coral reefs (tropical)	• habitat loss through: (1) increased mortality due to coral bleaching (2) reduced calcification rate, weakening corals & slowing growth (3) reef 'drowning', though shallow reefs limited by water depth may benefit		• *changes in community structure, decreased abundance & fisheries yields*	
	increased frequency & intensity of storms	marine – coral reefs (tropical)	• increased physical damage, with shorter recovery times between recurrences			
	warming, increased CO_2	marine – seagrasses (tropical)	• habitat loss or gain with changes in primary production			
Habitat quality & productivity	sea level rise, decreased precipitation	freshwater – (e.g. deltas, lakes)	• increased salinity		• increased metabolic stress, *resulting in reduced productivity*	Alheit & Hagen 1997; Attrill & Power 2001; Bakun & Broad 2003; Bakun 1990; Beamish *et al.* 1999; Botsford *et al.* 1997;Boyer *et al.* 2000;Brander 2000; Brody & Hlohowskyj 1998; Caddy & Rodhouse 1998; Chavez *et al.* 1999; Clark *et al.* 2003; Clemens *et al.* 1991; Cushing & Dixon 1976; Cushing 1982; Field *et al.* 1999; Fromentin & Planque 1996; Garcia & Le Reste 1981; Gitay *et al.* 2001; Grantham *et al.* 2004; Gray & Shaeffer 1991; Hare & Mantua 2000; Harris *et al.* 1992; Hobday & Tegner 2002; Jones
	changes in precipitation	saline lakes	• changes in salinity	• *reduced productivity*		
	warming, changes in precipitation	freshwater – lakes, rivers (temperate & tropical)	• decreased oxygen levels, increased nutrient concentrations, increased thermal stratification, reduced mixing, & reduced water quality in polluted lakes • reduced ice cover, increased oxygen levels	• increased primary productivity, *increased secondary productivity* • reduced diatom production	• *increased likelihood of mortality* • *changes in productivity & fisheries yields* • *decreased likelihood of winter mortality, increased productivity*	
	changes in precipitation, large-scale climatic variation (ENSO)	freshwater – floodplain (temperate & tropical)	• changes in inundation (& nutrient inputs)		• *changes in productivity & fisheries yields*	

Issue	Climate change variable	Ecosystem	*Impacts on:*			Example references
			Environment/ habitat	Phytoplankton/ Zooplankton	Fish/ Invertebrates	
	warming, large-scale climatic variation (ENSO, NAO, PDO), changes in precipitation, winds	marine (including upwelling systems) (temperate & tropical)			• changes in abundance, reproductive success, growth, productivity, & fisheries yields	1994;Justic *et al.* 1996; Kawasaki 1983; Klyashtorin 1998; Klyashtorin 2001; Lluch-Belda 1999; Lluch-Belda *et al.* 1992; Mackas *et al.* 1998; Meisner & Shuter 1992; Molfino & McIntyre 1990; Muter *et al.* 1995; O'Reilly *et al.* 2003; Ogutu-Ohwayo *et al.* 1997; Regier *et al.* 1990; Reid 2003; Richardson & Schoeman 2004; Roemmich & McGowan 1995; Romero & Melack 1996; Sagua 1993; Schindler *et al.* 1990; Scrimgeour *et al.* 1994; Sharp 2003;Tyedmers & Ward 2001; van Zalinge *et al.* 2003; Varis & Somylody 1996; Verburg *et al.* 2003; Waluda *et al.* 2004; Ware 1995; Zhang *et al.* 2000
				• changes in primary and/or secondary productivity	• *changes in abundance and fisheries yields*	
			• changes in stratification, mixing, oxygen levels, nutrient levels, currents & upwelling duration	• *changes in primary & secondary productivity*	• *changes in productivity*	
	warming, large-scale climatic variation (ACI, ALPI, AO, ENSO, NAO, PDO, SOI, TPI)	marine (temperate & tropical)			• long-term (e.g. decadal scale) fluctuations in abundance, productivity, & fisheries yields	
			• ecosystem 'regime shifts' (shifts from one state to another) in response to atmospheric regime shifts	• 'regime shifts' involving changes in relative abundance of species and/or timing, intensity, and duration of peak production	• 'regime shifts' involving large-scale changes in relative abundance of species; timing, intensity, and duration of peak production; and/or synchrony in productivity across large spatial scales (e.g. ocean basins, global)	

Table 5.1 has presented an overview of potential climate change effects upon fisheries. Considerable uncertainty remains, however, about specific physical and biological mechanisms underlying such effects, as well as about probable directions of change. Reasons behind this uncertainty include:

(1) *Uncertainty is inherent in assumptions about future environmental variability*. For example, much of our understanding of climate change effects on fish and fisheries is based on observations from El Niño events, periods of anomalous ocean warming in the Pacific basin (Trenberth 1997). An El Niño event, however, represents the warm phase of a broader cycle of variability that also involves periods of basinwide cooling (La Niña phases). Its effects may therefore not be directly comparable to changes arising from more sustained warming in the future (Reynolds *et al.* 2003).

(2) *Predictions about climate change effects on fisheries are sometimes conflicting.* An individual climate change variable can affect fisheries in opposite ways. For example, freshwater lakes have been predicted to increase in productivity across trophic levels with warming (Regier *et al.* 1990; Stefan and Fang 1993). Such increases, however, combined with increased thermal stratification, could exacerbate anoxic conditions, thereby resulting in higher levels of fish mortality and/or reduced nutrient supplies to the photic zone (Regier *et al.* 1990; Tyedmers and Ward 2001; Verburg *et al.* 2003). Understanding effects due to other variables (such as precipitation) is even more complicated, given that unlike temperatures, which are projected to increase globally, projected precipitation levels are much more variable regionally.

(3) Ecosystems are influenced simultaneously by many physical variables, with varying impacts upon fisheries. For example, the productivity of coastal upwelling systems would be expected to decline with warming, due to increased stratification, reduced mixing, and therefore reduced nutrient inputs to surface waters (e.g. Field *et al.* 1999). However, if future climate change results in stronger offshore winds, then mixing, nutrient levels, and productivity levels could increase (Bakun 1990).

(4) *Our understanding is largely based on historical observations, which may be limited spatially or temporally to allow longer-term, more general predictions.* Studies tend to be carried out over small spatial scales, and generate predictions which may not hold beyond the particular systems studied. For example, most of the detailed studies of environmental influences on freshwater lake systems focus on temperate lakes in North America, which may respond differently to climate change than will lakes in tropical regions. Similarly, relatively short time-scales of observation limit our ability to predict responses that will depend on longer-term processes. For example, the issue of coral bleaching represents one of the clearest examples of a link between temperature increases and habitat loss, with widespread coral mortalities reported as a result of recent warming events (e.g. Hoegh-Guldberg 1999; Sheppard 2001; Souter *et al.* 2000; Wilkinson 2002). Geographic variability in bleaching thresholds suggests that temperature tolerance may be evolving continually (Coles and Brown 2003; Hughes *et al.* 2003), and recent studies indicate that corals may be able to adapt to warmer temperatures by selectively hosting more thermally tolerant symbiotic algae species (Baker *et al.* 2004; Rowan 2004). However, rates of environmental change may be accelerating too quickly to allow such adaptation to occur (Hughes *et al.* 2003).

(5) *Many aquatic systems are already under considerable stress.* Existing pressures on aquatic systems may make them more vulnerable to climate change, and may in turn, be exacerbated by climate change (McLean and Tsyban 2001). For example, many of the world's stocks are already fully or over-exploited (FAO 2004), and therefore have a lowered capacity for resilience to environmental variation. Healthy coral reefs are likely to be better able to keep up with predicted rises in temperature and sea level, but those which have been degraded in other ways (e.g. sedimentation, pollution, and over-fishing) are less likely to cope (e.g. Wilkinson 2002).

(6) *Climate change effects are difficult to disentangle from natural background variability.* For example, large-scale atmospheric-oceanic variability occurs over interannual scales (e.g. ENSO), and longer-term (e.g. decadal) scales; the latter are typically referred to as 'regime shifts', with changes that cascade through trophic levels (e.g. Botsford *et al.* 1997; Polovina *et al.* 1994). Identifying effects on fisheries which are clearly attributable to climate change is challenging, particularly when climate change may influence patterns of occurrence of events such as El Niño (Timmermann *et al.* 1999).

Bearing these uncertainties in mind, Hulme et al (2003) have summarised potential climate change effects on lake and river ecosystems (Box 5.2)

Box 5.2 Potential climate change impacts on inland fisheries (adapted from Hulme et al., 2003)

There are large uncertainties in climate scenarios at the space and time-scales required for impacts assessment and further uncertainties involved in the translation from climate change to impacts on fisheries. Climate change directly affects important characteristics of lake, wetland and river systems such as: water levels; water temperature; thermal stratification; water quality; productivity; biodiversity. Indirect effects of climate change also affects fluvial systems through for example: changes in the characteristics of catchments (watershed) areas; and climatic influence on socio-economic activity in and around systems. In some cases current lack of understanding and limited availability of empirical case studies of fluvial processes and their interactions limits our ability to determine with confidence the impacts of climate change on freshwater ecology. Nevertheless there are certain generic relationships between climate and lacustrine systems that will be common to most situations. The following bullet points outline some of these generic links between climate and inland and coastal fluvial systems.

Rising average temperatures and changes in extremes.

- Rising air temperatures will increase surface water temperature and influence thermal stratification in rivers, lakes and wetlands. Warmer winters may affect mixing and nutrient recycling rates in temperate lakes as reduced seasonal cooling, which causes breakdown in the thermal density contrast, may be reduced.
- Higher frequency of extreme temperatures in summer (possibly exceeding thresholds) and reduced winter freezing in certain lakes are likely to affect thermal stratification and species composition.
- Higher surface air and water temperatures will increase open water evaporation rates and lead to a fall in water levels unless offset by increases in precipitation or changes in other factors that affect evaporation rates (see below).

Changes in the temporal and spatial characteristics of precipitation.

- The impacts will vary according to the direction and magnitude of precipitation change and the hydrological characteristics of the fluvial system.
- Endorheic (closed) and exorheic (open) lakes are very dependent on the balance of inflows and evaporation and may be very sensitive to change in either.
- Increases in precipitation, unless offset by higher evaporation, will increase lake inflows and lake levels. If extreme precipitation events increase in frequency this will lead to greater frequency of riparian flooding.
- The extent to which lake level fluctuations and change affect lake productivity and biodiversity varies according to local conditions of the lake and its catchment.
- Drier conditions, exacerbated by greater evaporation, will reduce lake inflows and lake levels. Hence, water quality, productivity and biodiversity are likely to be affected.
- Seasonal regimes may be reduced or enhanced, depending upon the nature and interaction of precipitation and evaporation change, with potentially significant effects on lake hydrology, ecology and management.
- Lakes fed by snowmelt rivers in spring are likely to see earlier and faster spring thaws leading to higher river flows and lake levels in this season.
- Changes in variability over longer timescales, e.g. decades, possibly associated with changes in behaviour of the El Niño-Southern Oscillation will also affect lake characteristics and management.

Changes in other climate variables, including radiation or cloud cover, relative humidity and windspeed.

- Data on factors affecting lake evaporation and catchment evapotranspiration other than temperature, namely relative humidity, cloud cover and wind speed over the lake and land cover in the contributing areas, were not available for this study.
- In some instances changes in these variables may cause marked changes in lake and wetland systems. Increased evaporation due to warmer temperatures may either be enhanced, for example by increases in windspeed and radiation, or offset (and sometimes even reduced) by increases in humidity and cloud cover.
- Changes in windspeed and prevailing wind direction will also influence mixing processes and thermal stratification in lakes. In tropical lakes mixing is more dependent upon evaporative cooling during the windy season.

Rise in sea-level.

- For low lying lakes and those with tidal influences rising mean sea-level and increasing magnitude and possibly frequency of extremes will be important.
- Increase in mean sea-level combined with possible changes in storminess will have wide-ranging impacts upon lacustrine and associated fluvial systems.
- Flooding, saltwater incursion, rivers backing up and increases in lake levels will dramatically alter lake hydrology, ecology and management.

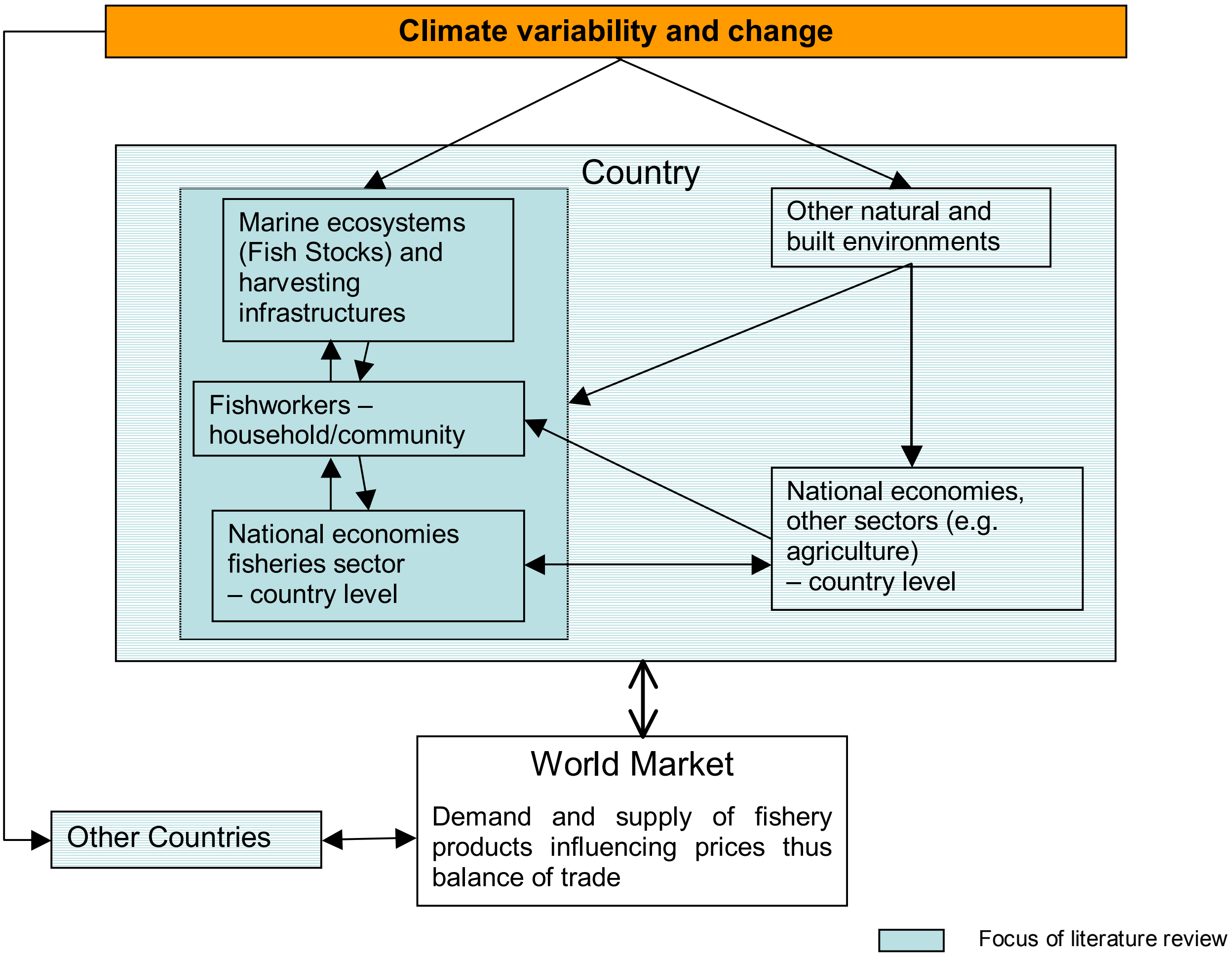
5.2.2 Links between climate change and variability and human impacts and responses

Given the uncertainties and multiple potential pathways linking climate change with fisheries production in biological terms (Table 5.1, above), the impact of global warming on the fisheries sector in socio-economic terms is further compounded by the dynamics of human responses. Not only, therefore, is there great uncertainty regarding the extent and speed of climate change and our knowledge of its biophysical impacts on fish stocks, but there is the added uncertainty of understanding how people and economic systems respond to climate-induced variability and change. Despite these uncertainties, understanding the livelihood impacts of climate change and the resulting vulnerability of fisherfolk is essential for the appropriate design of policies and management strategies in the fisheries sector. The main objectives of this section are therefore to present a review of available literature in order to (1) understand the impacts of climate change on harvest activities and more broadly livelihoods and (2) review (possible) adaptation strategies and the implications for fisheries management.

Systems are characterized by different scales. In the fisheries production system we have identified for our purposes two scales to assess the impacts of climate change: the local (household-community) level, and the sectoral or national level (the two sometimes, but not always, coincide). Arnason (2003) suggests that climate change may impact fisheries in at least two different ways: by altering the availability of fish to fishermen (direct impact) and by changing the price of fish products and fisheries inputs (indirect impact). In our review we first concentrate on impacts more directly related to harvesting activities and communities dependent on them for their livelihoods in economic, as well as social and cultural terms. We then assess more indirect (macroeconomic) impacts on national economies, and to a certain extent, regional or international markets. We did not survey literature that more broadly covered topics related to impacts on coastal and riparian zones or other economic sectors that may interact with fisheries, in order to narrow our literature search. However, we recognise that climate change is likely to have multiple impacts across sectors, and synergistic effects with other socioeconomic and environmental stresses (McCarthy *et al.*, 2001; O'Brien *et al.*, 2004). Additionally, different systems will interact with one another; the processes operating within one system possibly directly or indirectly affecting another system (Brooks, 2003). Based on these caveats, Figure 5.1 illustrates the methodology and scope of our literature review.

More than one hundred peer-reviewed-papers and general media articles were reviewed, as well as grey literature from national governments and international organisations. Studies reviewed were mostly observational and qualitative in nature, looking at past and current climate change and variability effects on the fishing sector, while few looked at future climate change scenarios and predicted impacts for the fishing industry. Impacts related to ENSO events (i.e. El Niño) were particularly well documented as well as impacts in Latin America, the Arctic and the Barents Sea regions.

Figure 5.1 Socio-economic impacts of climate change and variability on fisheries: methodology and scope of litterature review.



An illustrative overview of the results of the literature survey are given in Table 5.2 and these summaries are complemented by a brief textual review on the following pages.

Table 5.2 Examples of potential links between climate change-related phenomena and impacts on people involved in the fishery-harvesting sector

Environmental variable	Climate change scenario/event	Location	Impacts on marine ecosystems (fish stocks) and harvesting infrastructure (Direct impacts)	Impacts on the harvesting sector in terms of revenues, fishing costs and management (Indirect impacts)		Source
				Household – Community level	National Economies – sector wide and country level	
Storms and severe weather events	Hurricane Mitch 1998	Belize	• Mechanical damage to production and ancillary infrastructure.		• Loss of infrastructure to the fishing community estimated at US$1,214,015	Gillett, 2003
			• Main lobster and fin-fishing grounds in northern part of the country destructed.		• Translates to a loss in production of 65,000lbs for that year	Gillett, 2003
	Predicted increase in average wind speeds and in the frequency of storms	CARICOM region	• Rough seas, destruction of fish traps	• Impact of weather changes on fishing effort: marginal increase in non-fishing days leading to short-term reduction in catch per vessel and overall catch • Increasing travelling time leading to increasing fuel costs • Damage to gear and vessel leading to increasing maintenance costs		Mahon, 2002; Mahon and Joseph, 1997
	Hurricane Luis 1995	Antigua and Barbuda	• 16% of fishing fleet was destroyed or lost and 18% was damaged	• Loss of fishing capacity of about one third following the hurricane, at a time when food would be scarce	• Overall loss of revenues from the fishing industry of 24% of annual revenues	Mahon, 2002; Mahon and Joseph, 1997
			• Destruction and damage of tourist infrastructures	• Conflict between community members over scarce resources	• Dislocation of workers from other sectors into fishing for short-term employment, adding pressure on stock	Mahon, 2002
	Hurricane Hugo 1989	Antigua and Barbuda	• Mechanical damage to production and ancillary infrastructure.		• Total damages for the fishing industry assessed at US$1.15M	FAO, 1989 cited in Mahon, 2002
	Hurricane Gilbert 1988	Jamaica	• Mechanical damage to production and ancillary infrastructure.	• Loss of 90% of traps leading to loss of revenues and high costs of repairs		Aiken et al, 1992 cited in Mahon, 2002
	Predicted changes in seasonality and storminess	Atlantic Canada	• More storms, drier winters, more spring precipitation, stronger winds, inconsistencies in currents and winds	• May necessitate operational changes by fish harvesters, with implications for both health and safety and search-and-rescue operation		Catto, 2004

Environmental variable	Climate change scenario/event	Location	Impacts on marine ecosystems (fish stocks) and harvesting infrastructure (Direct impacts)	Impacts on the harvesting sector in terms of revenues, fishing costs and management (Indirect impacts)		Source
				Household – Community level	National Economies – sector wide and country level	
Increased rainfall		Caribbean - Trinidad and Tobago, Grenada, St Vincent and the Grenadines, and Barbados	• In 1999 unusual fish mortalities hypothetically attributed to unusually high rainfall in the Amazon and Orinoco river basin. This water mass stressed shallow water demersal/reef fish, causing mortality and/or susceptibility to diseases	• Closure of fishery activities resulting in loss of income for fishing communities.	• Impacts on the economy and public health of the affected islands became serious issues	Lum Kong, 2002; Siung-Chang and Lum Kong 2001
Change in ocean currents - ENSO events	Forecasted increase of ENSO events	Fiji and Kiribati	• Predicted shift in spatial distribution of tuna population affecting negatively Fiji while Kiribati remains more or less unaffected • Possible decline in total catch		• Increase or loss of revenues • Increase in prices	Aaheim and Sygna, 2000
		Caribbean	• Distribution and abundance of certain tropical large pelagic species are known to change during years of ENSO events leading to reduced fish yields	• Standard of living in the fishing communities affected due to decreased revenues	• Impact on efficiency of associate industry	Singh-Renton, 2002
	ENSO - El Niño 1972-73	Chile	• Sea surface temperature rose by nearly 3 degrees above normal leading to decrease in catches of anchovetta and cool-water species like sardines and hake. By June 1973 landing of anchovetta and sardines decreased to one-tenth of the volume of fish caught in normal years. • Inversely catches of tropical-water fish like swordfish increased.		• Ecological crisis combined with political one (overthrow of the Allende government) led to a concentration of the ownership of industrial fisheries. Rising costs and lack of foreign currency for purchase of equipment led independent operators to sell to larger companies or to come under the management of the government. • Increase in efficiency leads to a reduction of fishing vessels and personnel: the Chilean industry lost 29% of its labour force in a region where coastal communities highly depended on fishing for their livelihoods	Glantz and Thompson, 1981

Environmental variable	Climate change scenario/event	Location	Impacts on marine ecosystems (fish stocks) and harvesting infrastructure (Direct impacts)	Impacts on the harvesting sector in terms of revenues, fishing costs and management (Indirect impacts)		Source
				Household – Community level	National Economies – sector wide and country level	
Change in ocean currents - ENSO events (cont.)	ENSO - El Niño 1972-73	Peru	• Variation in fish stock		• In the 1970's collapse of the stock resulted in wide spread failure of firms in the industry and the creation of the Pesca Peru a government agency	Glantz, 1981
	ENSO - El Niño 1982-83	Peru	• Variation in fish stock - 1982-83 El Niño leading to decrease in catches of anchovetta and cool-water species like sardines and hake. • Landing of fishery products for human consumption decreased by 62%.		• The fishery net loss was US$ 8, 250 million and exports of fishery products decreased by 45% from January to May 1983	Palomino, 1984;
			• Population increase and the expansion of the distribution range of scallop and white and brown prawns. • Scallops catch rose by 920% in 1983 compared to 1980-82 and prawn catch rose 863% in 1983.		• Prices and exportation levels rose for those species • For approximately 20 years the fishery was almost monospecific - based only on anchovy (95.9% of the total accumulated catch). The effect of El Niño phenomena forced the change to a mutltispecies fishery and later on to a bispecific fishery (anchovy and sardine)	Palomino, 1985; Palomino, 1991
	ENSO - La Niña 1996	Peru	• Higher yields are experienced during cold events like La Niña		• In 1996 revenues from exports of anchovetta and sardine increased, due to increase in catches	Ordinola, 2002
	ENSO - El Niño 1997-98	Peru	• Increased rainfall	• Rural fishing villages unable to access markets because of washed out roads and bridges	• Swings in abundance are at odds with current management techniques	Pontecorvo, 2000; Pontecorvo, 2001; Broad et al, 1999;
			• Increased growth rate of octopus and scallops and appearance of tropical species like mahi-mahi	• Initially profitable to artisanal fishermen but lack of adequate gear limited benefits • % of catch put into social security and health organisation decreases, leaving fishermen with no safety net	• Decrease in price of mahi-mahi due to over-supply and economic situation in the Asian markets limited profits to the industry	Broad et al, 1999

				and access to finance		

Environmental variable	Climate change scenario/event	Location	Impacts on marine ecosystems (fish stocks) and harvesting infrastructure (Direct impacts)	Impacts on the harvesting sector in terms of revenues, fishing costs and management (Indirect impacts)		Source
				Household – Community level	National Economies – sector wide and country level	
Change in ocean currents - ENSO events (cont.)	Prediction of El Niño impact on the Aleutian Low	Alaska, Bering Sea, Yukon/Kuskokwim and Bristol Bay Regions	• Decrease in anadromous fish stocks due to changes in currents	• Affects economic and dietary well-being of subsistence users since fish represents 60% of wildlife resources harvested. • Decline in household income. • Decrease in commercial fishing income will prevent purchase of expensive store-bought goods.		Callaway et al, 1998
		Alaska	• Changes in species abundance • Changes in weather and ice conditions	• Changes in harvest for instance cost of retooling to harvest more abundant species • Changes in boat, gear, permit and IFQ values • Affect where and when fishing is physically possible as well as the costs of fishing	• Changes in regulations due to effect of climate on other species. E.g. potential climate-related declines in Steller Sea Lion populations led to proposals for significant restrictions on the Alaska pollock fishery in 1998. • Changes in processing costs • Changes in prices but also depend on how climate change affect harvests of competing species in other parts of the world • Political conflicts over formal or informal harvest allocation	Knapp et al, 1998
Increase in average surface temperature and increase in year-to-year climate variability	Forecasted temperature changes	Pacific Islands	• Decline in tuna abundance due to decline in primary productivity, especially i bigeye tuna • Spatial redistribution of tuna resources to higher latitudes		• Longline fishing pressure on adult yellowfin tuna will increase due to decline in adult bigeye leading to unsustainable exploitation if fisheries not well managed • Distant water fishing fleets should be able to adapt to	World Bank, 2000

		CARICOM region	• Effect of temperature on growth and mortality & therefore biomass and production. • Affects migratory routes and distribution patterns, thus availability of stock.	• Loss of revenues due to decreased catches • Unavailability of stock or increased costs to reach fishing grounds	changes in the spatial distribution and abundance of tuna fish stocks but domestic fleets (restricted to EEZ) will be more vulnerable to these fluctuations	Mahon, 2002

Environmental variable	**Climate change scenario/event**	**Location**	**Impacts on marine ecosystems (fish stocks) and harvesting infrastructure (Direct impacts)**	**Impacts on the harvesting sector in terms of revenues, fishing costs and management (Indirect impacts)**		**Source**
				Household – Community level	**National Economies – sector wide and country level**	
Increase in average surface temperature and increase in year-to-year climate variability	Forecasted temperature changes	Norway, Barents Sea	• Increase of mean sea temperature of 2 degrees C • Increased growth rates of 20% for cod and herring and increased recruitment • Changes in the Gulf Stream, reduction of sea temperature of 3^0C. • Recruitment growth and distribution of cod and herring altered (25% reduction in growth rate).		• Higher catches modelled resulting in an increase of 1% in total number of jobs in North Norway compared to current employment figures • Total income generation in the North Norwegian economy is increased by 1.3% • Lower catches modelled resulting in a reduction of 0.8% in total number jobs compared to current levels of employment. • A reduction of 0.8% in terms of income generation	Eide and Heen, 2002
		Iceland	• Warming leading to gradual increase of fish stocks (20%) over 50 years (optimistic scenario) • Warming leading to decrease of fish stocks by 25% over the next 5 years (dramatic scenario)		• 0.4% increase in the value of fish production annually • In the short term GDP reduced by 9% but over time reduction of GDP only 3%	Arnason, 2003

	Experienced temperature changes	North Pacific, US Canada	• Divergent trends in Northern and Southern salmon abundance due to changes in ocean temperatures and circulation patterns		• Abundance-based management agreement (Pacific Salmon Treaty) between US and Canada affected by climate variability and led to conflicts in management of stocks. Thus transboudary management of resource affected	Miller et al, 2000, Miller 2000
		Newfoundland, Canada	• Warmer temperature and low water levels in rivers over 25 years (1975-1999)	• On average 28% of salmon rivers closed annually, up to 70% in some years. Loss of 35-60% of potential fishing days between 1995 and 1999.	• Increased closure due to climate change will affect the economic importance of recreational salmon fishery	Dempson et al, 2001

Environmental variable	Climate change scenario/event	Location	Impacts on marine ecosystems (fish stocks) and harvesting infrastructure (Direct impacts)	Impacts on the harvesting sector in terms of revenues, fishing costs and management (Indirect impacts)		Source
				Household – Community level	**National Economies – sector wide and country level**	
Increase in average surface temperature and increase in year-to-year climate variability	Experienced temperature changes (cont..)	Gulf of Maine	• From 1995-2002 waters of Boston were 2°C warmer than their historical level • Lobster average catches have been declining (i.e Connecticut catches dropped by 59% and New-York State by 75% between 1999 and 2002). Warmer temperatures linked with a weaker immune system, increasing mortality of lobster	• Connecticut lost 40% of its lobstermen; livelihoods are being disrupted in a coastal region were lobster fishery is at the heart of the economic activity		Donn, 2004
		African Great Lakes	• Thermal stability of lake affected, contributing to reduction of fish stocks	• Threatens availability of dietary protein for local communities		Ogutu-Ohwayo et al, 1997
		Alaska	• Average temperature in Alaskan waters are up to 5 degrees Fahrenheit, salmon increasingly susceptible to diseases	• Arctic pack ice is disappearing, making food scarce for sea animals and causing difficulties for native hunters		Rosen, 2004
Sea-level rise	Predicted SLR in the Caribbean	CARICOM region	• Erosion of beaches/loss of fish habitats	• Beach seining depends on appropriate beach and near shore bottom conditions and could be affected by erosion. • This fishery is usually directed on local consumption, being important for local food security. Also elimination of appropriate landing sites		Mahon, 2002
	Predicted SLR	Gambia and Cote d'Ivoire	• The autonomous port of Abidjan (CI) which includes a fisheries port is currently threatened by erosion and 1 m SLR could be highly damaging.		• Coastal infrastructure related to fishing sector affected.	Jallow et al, 1999

Impacts of climate change on livelihoods – community level:

The principles of the sustainable livelihoods approach (SLA) were used to frame our analysis of the results of our literature search that relate to the local scale. The SLA, developed in the 1980's is now widely used in development projects (DFID, FAO, CIDA). A livelihood can be defined as the capabilities, assets and activities required for means of living (Chambers & Conway, 1992). The concept of sustainable livelihoods seeks to bring together the critical factors that affect the vulnerability or strength of individual or family survival strategies. The SLA framework has recently been widely applied in understanding the dynamics and poverty profiles in small-scale fisheries (Allison & Ellis, 2001; Neiland & Béné, 2004). Climate-induced changes to resource flows can fundamentally affect the viability of the livelihoods of the poor (SEI *et al.*, 2003). There is a need to improve the understanding of what makes fishers vulnerable to events and factors that result in poverty, and what makes it difficult to improve livelihoods, as well as what adaptive strategies and potential solutions exist in the context of climate change. In the climate change literature the concept of livelihoods is employed to understand the vulnerability context of communities (Adger, 1999; Morris *et al.*, 2002; Ziervogel & Calder, 2003), with work on fisheries focusing on climate variability, fluctuating stocks and livelihoods systems (Allison et al, 2001; Sarch & Allison, 2000). Different types of climate change impacts on fisherfolk communities can be linked to the various elements of the livelihoods framework such as impacts on assets and impacts on livelihoods activities. People can access, build and draw upon five types of capital assets: human, natural, financial, social and physical (Box 5.3), and here we examine how each is affected by climate change, based on the literature surveyed.

Box 5.3 Livelihood asset classification

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 and 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.

Source: Badjeck (2004) adapted from DFID (2001) and Scoones (1998)

Changes in natural capital:

Impact on revenues

A commonly cited consequence of climate variability and change is decreased revenues for fishermen due to decline in total catch and stock abundance (Callaway *et al.*, 1998; Knapp *et al.*, 1998; Luam Kong, 2002; Mahon, 2002; Mahon & Joseph, 1997). Loss of revenue can also be the result of the closure of fisheries activities during a weather anomaly related to climate change (Luam Kong, 2002; Siung-Chang & Lum Kong, 2001) or the reduction of fishing days due to increased weather variability (i.e. increased frequency of storms) (Broad *et al.*, 1999; Mahon, 2002).

Nevertheless climate change could also increase revenues with increased catches of certain species. The arrival of tropical species such as mahi-mahi and shark and the increased growth rate of octopus and scallops in Peru during the 1997-1998 El Niño event was initially highly profitable for the artisanal fisheries sector (Broad *et al.*, 1999, 2002). This was similar to population increases in the El Niño event of 1983 where scallop catches rose by 920% in 1983 compared to 1980-82 (Palomino, 1985). However, several factors undermined potential benefits to fishermen of additional species in 1997-98: the market price of mahi-mahi dropped to below US$1 due to over-supply, the 'Asian crisis' decreased export demand, and there was lack of adequate gear (Broad *et al.*, 1999).

Impact on harvesting costs

Change in migration routes and biogeography of fish stocks can affect fishermen's fishing effort; for instance increased travelling time will lead to increased fuel and ice costs (Mahon, 2002). Dalton (2001) linked fluctuations in sea surface temperatures (SST), including El Niño events, with fishing effort in the albacore tuna, Chinook salmon, sablefish and squid fisheries in Monterey Bay, California, using a predictive model. Under a scenario of SST corresponding to the ENSO events of 1983 (increase of 1.2 degrees Celsius), fishing effort decreases by 60% for the sablefish fishery and 400% for squid fishery (Dalton, 2001). This dramatic fall in the squid fishery is partly explained by the forward-looking behaviour of fishermen: prices only decrease by 50% but squid harvesters' expectations of increased costs due to increased SST decrease the number of boats (Dalton, 2001).

Changes in species abundance could also lead to changes in harvest and processing costs due to retooling (change of gear, boat) to harvest the newly abundant species (Broad *et al.*, 1999; Knapp *et al.*, 1998). Artisanal fishermen with limited resources will be particularly affected due to their incapacity to quickly adapt to new harvesting techniques and tools.

Damage to physical capital:

Decreased harvesting capacity

Storm and severe weather events can destroy or severely damage infrastructure and equipment such as port, landing sites and boats (Jallow *et al.*, 1999). For instance during hurricane Gilbert in 1998, Jamaican fishermen lost 90% of their traps resulting in a loss of revenue and high cost of repairs, as well as the inability to resume fishing activities promptly (Aiken *et al.*, 1992). In Antigua and Barbuda 16% of the fishing fleet was destroyed or lost while 18% was damaged due to Hurricane Luis in 1995 (Mahon, 2002). In Belize losses to the fishing community as a consequence of Hurricane Mitch (1998) have been estimated at US$ 1.2 million, in the form of loss of fishing gear and associated infrastructure (Gillet, 2003).

Decreased access to markets

Climate change can have an impact on transportation and marketing systems (Catto, 2004). In Peru, during the El Niño of 1997-98, many of the rural fishing villages were damaged by the heavy rains and were unable to get their products to markets due to washed out roads and bridges (Broad *et al.*, 1999).

Reduced financial capital:

In Peru, at the time of the 1997-98 El Niño event, a percentage of the catch was put into a recently privatized social security and health organisation for the industrial fishermen (Broad *et al.*, 1999). As a result of decreasing catches the agency's coffer quickly ran dry (Broad *et al.*, 1999, p.15). This left fishermen without a safety net and access to financial resources to cope with the difficult economic situation.

Reduced human capital:

Health and Safety

Injury and death are the direct health impacts often associated with natural disasters linked to climate change events such as increased frequency and severity of floods and hurricanes. In the case of injury, there is an obvious impact on human capital through the resulting reduction in the physical capabilities of fishermen to pursue their livelihoods. Studies have also shown that the El Niño cycle in certain areas is associated with changes in the risk of diseases transmitted by mosquitoes, such as malaria and dengue fever, and disease caused by arbodviruses other than dengue virus. The risk of malaria in South America, Central Asia, and Africa (areas where the majority of small scale fishermen are located) has been shown to be sensitive to variability in climate driven by El Niño (Patz & Kovats, 2002). Small coastal rural communities often lack potable water, sewage and drainage: health sector problems are thus often enhanced by climatic events such storms, floods and ENSO events. Additionally marine phytoplankton blooms caused by increased sea surface temperatures result in red tides that cause diarrhoeal and paralytic diseases linked to shellfish poisoning (Hales *et al.*, 1999; Patz, 2000).

Safety while pursuing fishing activities is a significant issue in fishing communities because of predicted changes in weather and storm events or, in the case of Arctic communities, stability and safety of ice and snow. Indeed personal safety in Arctic communities practicing ice fishing is jeopardized by unpredictable ice conditions in winter making travel dangerous (Berkes & Jolly, 2001). Catto (2004), presenting the impacts of climate change for Atlantic Canadian fisheries communities, also puts forward that changes in seasonality and storminess may necessitate operational changes by fish harvesters, with implication for both health and safety search-and-rescue operations.

Food Security

Impacts on food security related to access and availability of important traditional food species could be significant in a scenario of decreased catches due to climate change events. The risk of malnutrition and undernutrition for communities highly dependent on fish as a source of protein (Ogutu-Ohwayo *et al.*, 1997), combined with changes in diet (reduction of protein from fish source) are some of the possible effects. Decline in commercial fisheries, leading to decrease in income, can also reduce the ability to purchase store-bought food during periods of natural resource scarcity (Callaway *et al.*, 1998).

Unemployment

Reduction of catches and collapse of stock can lead to unemployment. In Connecticut catches of lobster fell by 59% between 1999 and 2002. This was linked to increased sea surface temperature in the Gulf of Maine and resulted in the loss of 40% of the lobstermen (Donn, 2004).

Social capital:

Displacement and increased migration

Increasing frequencies of droughts are forecast in Southern Africa, leading to greater variability in lake levels and river flows, affecting lakeshore and river floodplain livelihoods that incorporate fishing (Conway et al., 2005). Under increasing uncertainty, migratory fishing (moving between waterbodies) becomes a more rational livelihood strategy than investing in a stable village-based existence. Drought affecting agriculture may also push people out of agriculture and into fishing (e.g. Senegal in the late 1990s). Increased levels of displacement and migration put a strain on communal-level management and resource access systems, while decreasing commitment to stable settlement affects investment in community level institutions and services.

Increased conflict over scarce resources

Mahon (2002) observed that in Antigua and Barbuda, during Hurricane Luis in 1995 the destruction and damage of tourist infrastructures resulted in the transfer of workers from this sector into fishing for short term employment, adding pressure to fishing stocks and labour supply. This displacement of workers can lead to friction within communities.

Impact on national economies – national/regional level:

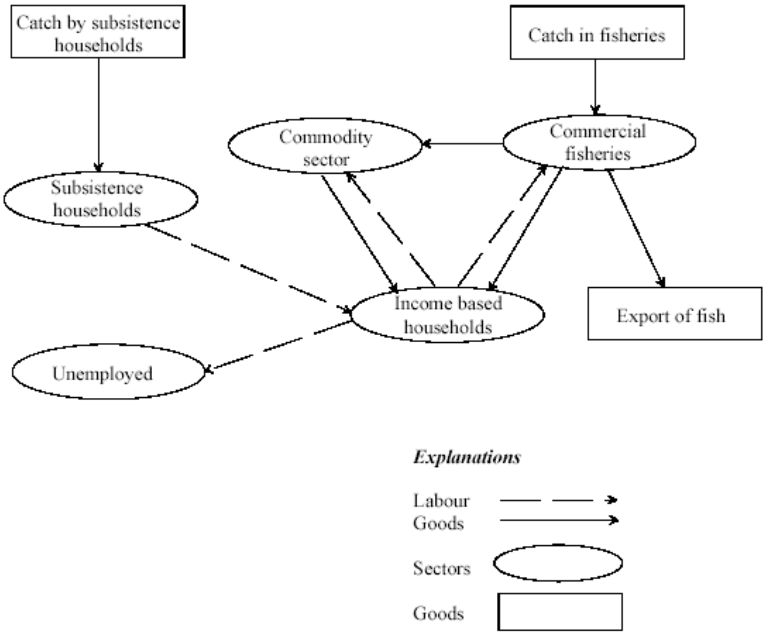
Observed macroeconomic effects of climate variability: the case of Latin America and the Caribbean

Macroeconomic consequences (indirect, larger-scale economic effects) of changes in the fisheries sector range from impacts on the labour market and the need for industrial re-organisation, to loss of export earnings to national economies due to decline of catches (Glantz & Thompson, 1981). In Chile, the El Niño event of 1972-1973 created an inflated demand for fish derivates (fish meal and fish oil) which led to an increase in prices (325$ per ton in 1975 compared with 90$ per ton in 1955) (Glantz & Thompson, 1981). The Chilean government and the producers attracted by the possibility of a healthier balance of payments, increased production and lowered costs. This ‘rationalisation’ of the fishing industry resulted in a reduction of 29% of the labour force in 1975 compared to 1970, while production levels remained the same (Glantz & Thompson, 1981). In Peru, during the El Niño event of 1982-83 decreases in catches led to a decrease in export of fishery products of 45% from January to May 1983, and the fishery net loss was estimated at US$ 8, 250 millions (Palomino, 1984). The previous El Niño-influenced anchovy collapse in 1973, coupled with political change in the country, led to a temporary nationalisation of the fishery resulting in massive layoffs and restructuring of the industry (Broad *et al.*, 1999), with the creation of the government agency Pesca Peru (Glantz, 1981; Pontecorvo, 2001). However, ENSO events do not always lead to negative impacts such as loss of revenues for national economies. For instance in 1996 Peru experienced higher revenues from exports of anchoveta and sardine which could be attributed to higher yields caused by La Niña (Ordinola, 2002).

Forecasted macroeconomic effects based on simulation studies: the cases of Fiji and Kiribati and North Atlantic fisheries

Aaheim and Sygna (2000) when assessing the likely economic consequences of a change in the tuna fisheries in the Pacific Ocean resulting from predicted climate change, use a simple macroeconomic model. The model divides the economies of Fiji and Kiribati into two production sectors, fish and other commodities and two household sectors, income based households and subsistence households (Figure 5.2). The model uses alternative scenarios for the price of fish, catch in commercial fisheries, and catch in subsistence households and a change in the cost of the fisheries. Under a scenario of reduction in catches by subsistence households, this section of the economically active population supply their labour to the production sector, resulting in a reduction in wage levels and increasing demand for labour. If fish export earnings are reduced, profits from the production of commodities increase, leading to a general increase in the economic activity. Thus, if there is an initial increase in demand in the supply of labour, unemployment decreases in the end (Aaheim & Sygna, 2000). This is at odds with findings presented above, highlighting the fact that indirect economic impacts of climate change will depend on the extent to which economies are able to adapt to new conditions.

Figure 5.2 Structure of macroeconomic model to examine climate-induced changes in fish catches in Fiji and Kiribati (Aaheim & Sygna, 2000)



A study by Eide and Heen (2002) on the potential impacts of global warming on the fishing industry in North Norway used two different models and a range of possible environmental scenarios and their impact on growth rate of cod stocks (Eide & Heen, 2002). Under a scenario of higher catches, income generation is increased by 1.3% and employment by 1% compared to current figures. More specifically, when calculating the multiplier effect, an increase (change) in the employment in the fish processing industry by 1, has been estimated to lead to a total employment increase in the North Norwegian economy (Mariussen & Heen, 1998). Lower catches result in a reduction of 0.8% of the total number of jobs as well as in terms of income generation. Eide and Heen (2002) point out that the annual catches are determined by quota regulations, which is the same in all scenarios, highlighting the fact that if global warming can have significant macroeconomic effects, changes in management play a more important role.

Implications for fisheries management: issues of adaptation and mitigation

The amount of research effort exerted on identifying the links between climate parameters and biological and physical oceanographic and hydrological factors stand in marked contrast to the paucity of studies of the effects of climate variability and change on fishery management systems.

In Peru IMARPE managed the 1997-1998 El Niño in a more prudent manner based on their experience of the 1973 events. After the 1973 collapse the Ministry of Fishery (MIPE) was empowered to exercise tighter regulation and management of marine resources(Zapata & Broad, [undated]). The financial difficulties facing the fishing industry are daunting and were exacerbated by El Niño. Privatization of the fishing sector in the 1970's was characterised by a high participation of national capital financed by lending from banks (Zapata & Broad, [undated]). The entire fishing industry is riddled with unpaid debts, which collectively constitute a significant portion of the banking industry's bad debt load that led to the quasi-crisis of liquidity in 1999 (Zapata & Broad, [undated]). El Niño has revealed the fragility of a privatisation process that favoured Peruvian industrialists who leaned heavily on the banking system and made no provision for the impacts of El Niño on catches (Zapata & Broad, [undated]). This illustrates that climate events such as El Niño must be considered by fisheries management agencies and the industry as a recurrent event rather than anomalous one.

In the case of Peru, relatively limited proactive measures aimed at minimising the negative and enhancing the positive impacts of ENSO events on the fisheries sector were implemented, which many attribute to the government's more recent economic policy of minimal intervention in the activities of the private sector (Broad *et al.*, 1999). Of the US$ 162 million spent by the government on preventive actions, only US$ 4.1 million was spent on the fishing sector (Broad *et al.*, 1999). In the case of fisheries, forecasting did not prevent massive labour disruption, increase in illegal fishing and apparent biological and economic collapse of the fishery, at least in the short term (Broad *et al.*, 1999). While the government implemented several fishing bans ('vedas'), industrial and political pressures cut the vedas periods short (Broad *et al.*, 1999).

In Mexico, climate variability has tended to be absent as a factor informing management decisions. This has led to development of a highly specialised and technologically rigid industrial fishing fleet that stand in contrast to the diversified multiple species multiple gear traditional fishers (Vasquez-Leon, 2002). This group of fishers perceives climate variability as a key factor that may have a direct impact on the abundance or decline of resources; measuring and quantifying climate variability is at the core of their adaptation strategies and draws on their collective, traditional knowledge. In terms of long term sustainability, the ability to shift from one species to another makes diversified fishers more capable of dealing with declines in the productivity of one species in a way that will prevent stock depletion as a result of excessive fishing effort. They have the mechanisms set in place to deal with unpredictability and what matters is knowledge and experience on how and when to capture a wide variety of species so that fishing can be sustainable. Access to fishing knowledge, which largely determines the ability of a fishery to diversify successfully, is key to reducing vulnerability. From an institutional perspective, system-wide adaptation can be supported through insurance, subsidies or other government aid. The small-scale diversified fishers, while they are better able to adapt to the uncertainties of fisheries, are more vulnerable as the Mexican government withdraws support from this sector in favour of the industrial sector.

Conclusions:

Among the primary findings of the literature review were the following:

- Most of the literature on global warming and fisheries does not focus on socio-economic dimensions and impacts on livelihoods. Additional research should be conducted to explore the impacts of global climate change and variability on fishing communities.

- There is a lack of quantitative studies and studies forecasting possible impacts of climate change based on simulation studies. Efforts should be put into developing ‘plausible futures’ scenarios for communities identified as highly vulnerable to climate change combining qualitative insight and quantitative information.

- Negative impacts are extensively presented in the literature while positive impacts of climate change on the fisheries sector are seldom highlighted. The impacts of climate change will not be distributed equally. There will be relative winners and losers from the impacts of climate change, for instance some communities may suffer significant losses while other will be less affected- or may even benefit, and this must be investigated further.

- There is a lack of studies (especially in peer-reviewed literature) focusing on Asia and Africa despite the fact that the majority of small-scale fisheries are located there. While anecdotal evidence is available, few studies investigate the effects of climate change and variability of livelihoods of poor fisherfolk in these regions. Additionally, the majority of the work reviewed focuses more on industrial, large scale fisheries.

- While the body of literature on adaptation and impact response to climate change is growing, there is little evidence on systematic research into adaptation and coping strategies in the fisheries sector.

- While the literature on fisheries management under uncertainty and management of fluctuating fisheries is significant, literature integrating and directly addressing climate change and fisheries management is still sparse. Uncertainty is inherent to fisheries management and managers already face difficulties in designing effective policies to ensure sustainability of stocks. While climate change could be considered as just ‘another added problem’, it is essential to increase research that develops management strategies under scenarios of global environmental change.

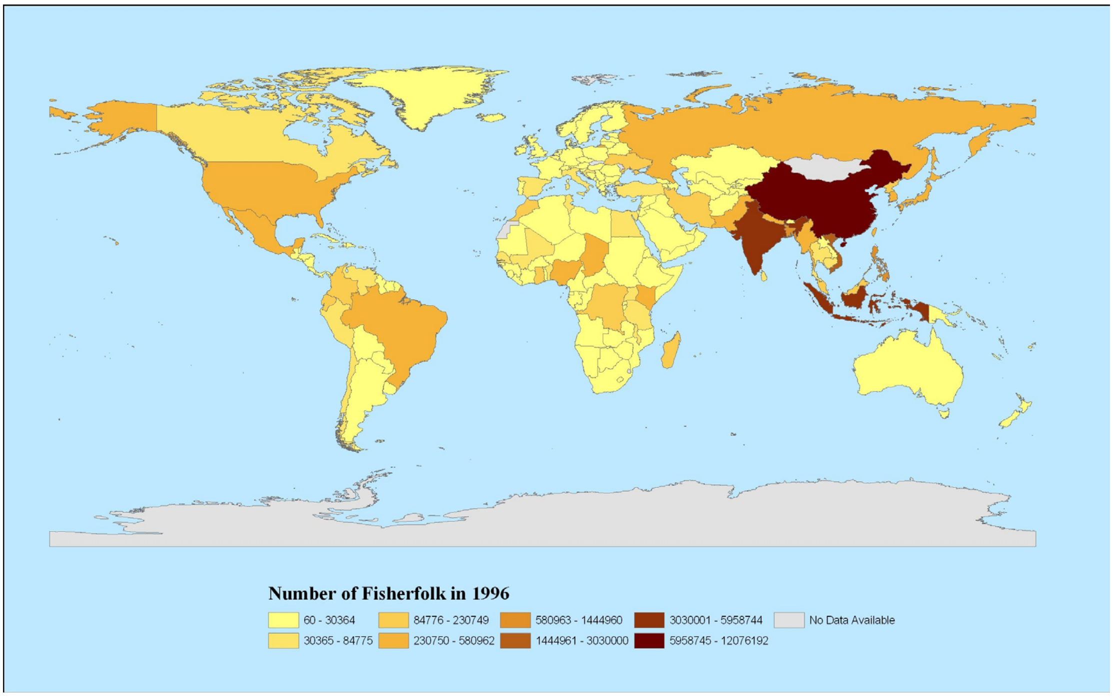
5.3 Mapping vulnerability at global level

Global climate change scenarios from IPCC (summarised in Box 4.1) suggest that the Asian landmass, the Amazon basin and the Western Sahara are the regions most exposed to climate change (highest predicted temperature change), but the level and distribution of projected temperature change varies according to different scenarios for projected economic growth (see Annex 1 for data). For this exercise, we used two contrasting scenarios for future economic growth: scenario A1F1 – high rates of economic growth throughout the world (reduced inequality), based on fossil-fuel consumption, but also on rapid uptake of new technologies, coupled with low rates of population growth; and scenario B2 – more moderate rates of economic growth based on locally different trajectories for development based on differing growth potential and population growth rates.

We do not present the full series of maps here, but instead select from the series of maps and tables we have created. The full dataset is given in Annex 1.

The first point to be emphasised is that the vast majority of the world's fisherfolk are found in Asia (Figure 5.3) and that their distribution mirrors that of population distribution more generally, with China, Indonesia, India and Vietnam being the four countries with the largest number of fisherfolk and also being among the largest and most populous countries with significant coastal zones and inland water resources. Bangladesh does not feature because most of its fisherfolk are part-time and likely to be registered as farmers in census data.

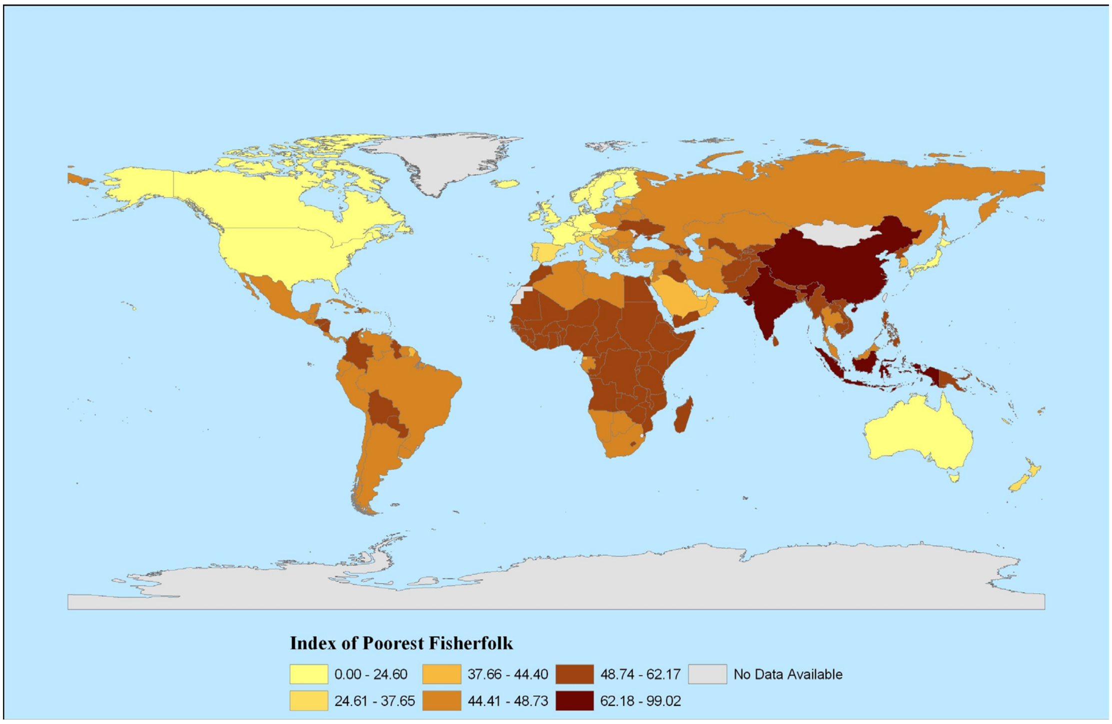
Figure 5.3 Global distribution of fisherfolk (people working in the fish capture and aquaculture sectors)



Data sources: FAO (2002).

In the absence of comparable national-level data on fisherfolk's levels of poverty, we derive an index that combines a measure of poverty at national level (per capita GDP) and the number of fishermen to identify the countries where there are likely to be the greatest number of fisherfolk living in poverty (Figure 5.4).

Figure 5.4 Index representing the global distribution of fisherfolk likely to be living in poverty



While the major fishing nations of Asia continue to have the highest values (thereby contributing to the composite 'sensitivity' index, below), it is clear that once poverty is considered together with the number of fisherfolk, the distribution of 'sensitive' countries begins to change – Bangladesh, Pakistan, Cambodia, the Philippines, some of the former Soviet republics around the Black Sea, Honduras, Colombia, Bolivia and most of Sub-Saharan Africa are included in the higher-index categories, while large countries with important fisheries, but where fisherfolk are unlikely to be living in absolute poverty, such as the USA, have lower index values (Figure 5.4).

Nutritional dependency is another contributor to the sensitivity index. Many of the most nutritionally dependent countries are small and medium-sized island states. The populous major fishing nations of Ghana, Indonesia and Bangladesh are also represented among the most dependent countries (Table 5.3) and West Africa emerges as being particularly nutritionally dependent on fish. This dependence is highlighted by a recent study indicating that when fish resources are scarce (e.g. due to market and climate fluctuations) the demand for protein is met by increased consumption of bushmeat (Brashares et al., 2004), to the concern of conservationists. This illustrates the knock-on effects of climate change on fisheries. Such links are likely to be numerous and difficult to identify, let alone quantify.