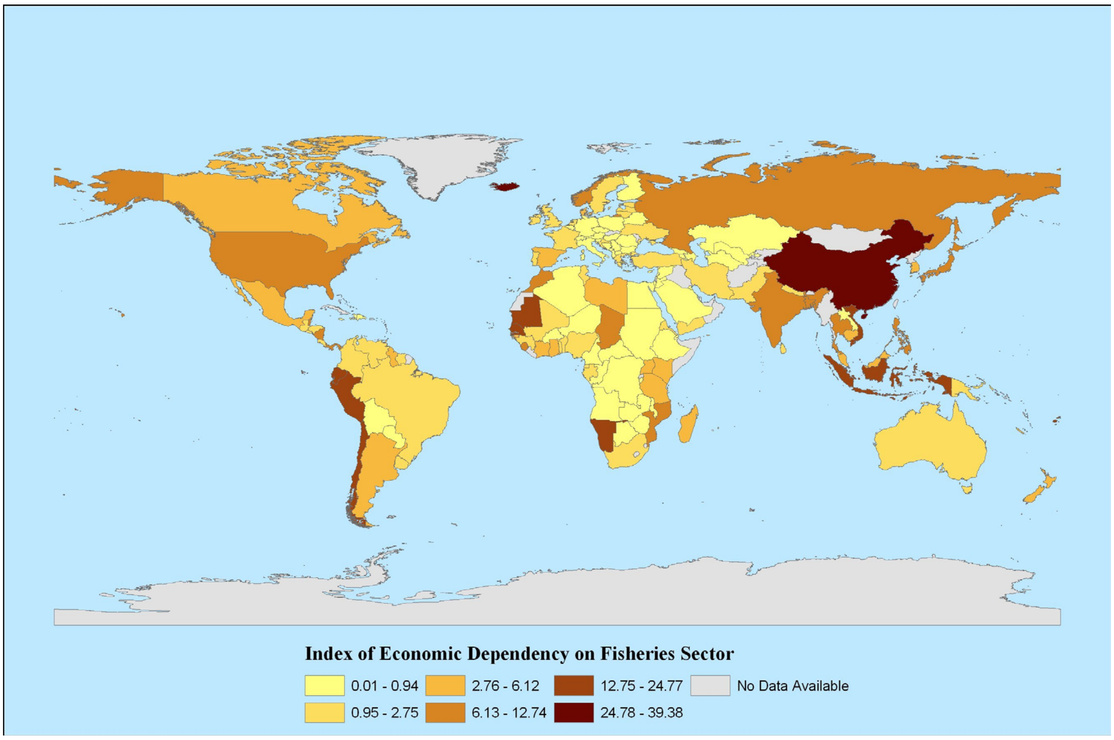
Table 5.3 The twelve countries with the highest level of nutritional dependency on fish.

	Nutritional dependency index
Maldives	100
Solomon Islands	95
Ghana	79
Comoros	73
Sierra Leone	72
Kiribati	72
Gambia	69
Indonesia	68
Sri Lanka	62
Sao Tome and Principe	60
Bangladesh	58
Seychelles	56

Note: calculated from per capita consumption and proportional contribution of fish to total animal protein intake. All indices are scaled to 100 (highest level of dependence) to allow composite indices to be calculated.

Economic dependency on fisheries is assessed by combining production (catch statistics) and export revenues generated by fishery products (Figure 5.5)

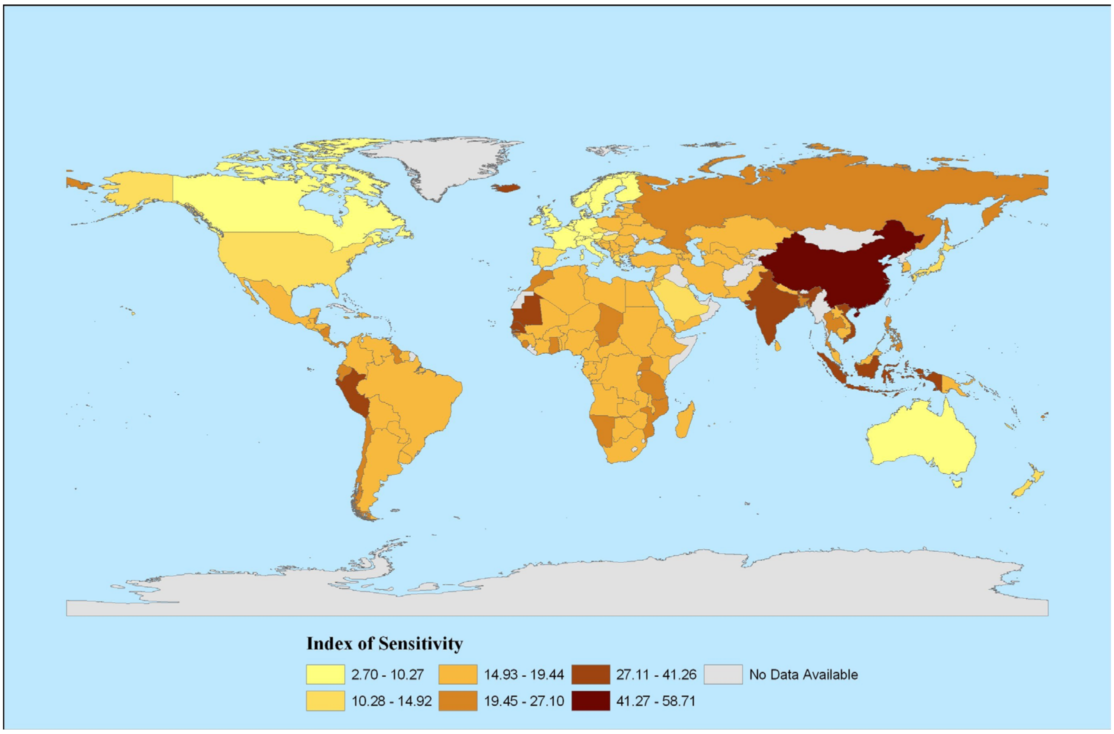
Figure 5.5 Index of economic dependency on fisheries (derived from catch statistics and export revenues generated)



The countries where fisheries make the greatest contribution in terms of a composite of production and export revenue generation are China, Vietnam, Indonesia, Mauritania and Namibia and the countries on the Western coast of South America.

Sensitivity to climate change in the fisheries context is here taken to be related to the contribution that fisheries makes to poverty prevention and poverty alleviation through provision of livelihoods to the poor, through contributions to nutrition (consumption) and through contributions of catches (production) and export revenues. These indexes and indicators of sensitivity are combined to create a global map of sensitivity (Figure 5.6)

Figure 5.6 Composite index of sensitivity of national economies to fisheries-sector changes

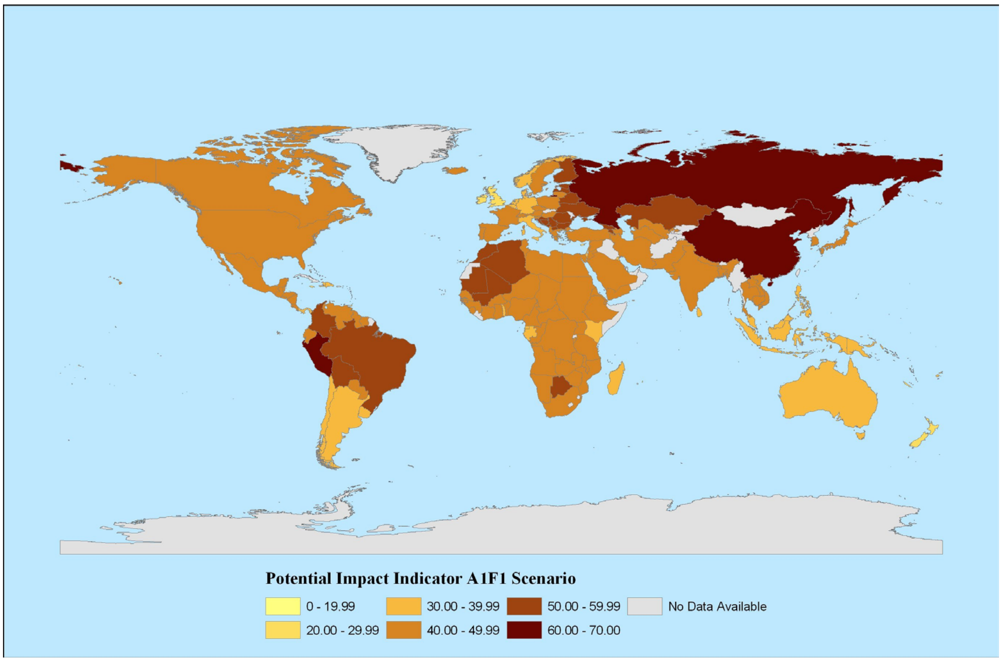


The most sensitive countries are, in Asia: China, Indonesia, India and Vietnam; in Africa: Mauritania; and in Latin America: Peru. Iceland is the most sensitive country in the developed world

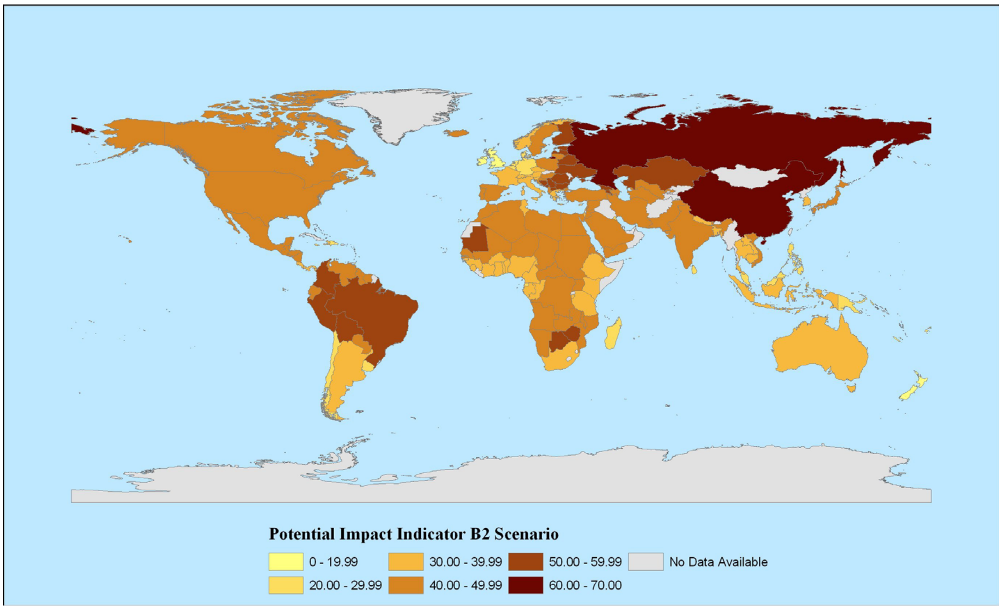
When sensitivity is combined with climate change exposure, we have an indication of the countries where climate change's influence on the fisheries sector is projected to have the greatest impact on the national economy (Figure 5.7). The A1F1 scenario projects impacts to be greatest across the countries making up the Central and Northern Asian landmass, the Western Sahel and the tropical regions of South America as being the most potentially affected (Figure 5.7a), while the B2 scenario shows a similar but less pronounced impact (Figure 5.7b).

Figure 5.7 Potential Impact of Climate Change (Exposure + Sensitivity) for Exposure to global warming: projected temperature rises (^{O}c) 1.5 m above the Earth's surface in 2050 under two contrasting IPCC scenarios

a) A1FI – Fossil-fuel intensive high levels of economic growth throughout the world (see Box 4.1 for full description of scenario)



b) B2 – 'local development' – more modest economic growth based on diverse local strategies for development (see Box 4.1 for full description of scenario)



Source: Hadley GCM Country-specific values were derived by Mitchell et al. (2003), based on gridded values from the Hadley Centre's HadCM3 climate model outputs.

Combining risk exposure, sensitivity and adaptive capacity gives a composite index of vulnerability. The analysis (Table 5.4) 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 in upwelling areas with important fisheries, such as Angola and Mauritania, top both lists.

Table 5.4 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. With risk exposure, sensitivity and adaptive capacity given equal weighting in the analysis, those countries with presumed low adaptive capacity (i.e. states with low HDI and GDP) dominate the lists, rather than states known to have major fisheries sectors. Given the fishery-sector focus, it would be justifiable to weight the analysis in favour of sensitivity, but more work is needed to establish appropriate relative weightings.

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

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

Given the complexity of linkages between climate change and effects on fisheries (Section 5.2) and the simplifications and loss of detail that results from national-level generalisations (Section 5.3), much operationally useful research will need to focus on making links between climate change scenarios, fishery impacts and livelihood and institutional responses for specific regions and/or habitat types. To indicate possible avenues for further research, we present three case studies that combine simulation with empirical observation to elucidate potential impacts of climate change on fisheries of the world's coral reefs, the lakes of Southern/Eastern Africa and the river floodplain fisheries of South and Southeast Asia (with a focus on Bangladesh). These three fishery types span a range of ecosystem types and geographical areas but all are important to small-scale fisherfolk living in poverty.

5.4.1 Coral reefs

Introduction – Climate Change and Coral Reefs
Carbon dioxide levels are predicted to double by 2100 and the emerging consensus is that this will result in a 3°C rise in global temperature (range 1.5°C and 4.5°C) (Kerr, 2004). Rising sea temperatures are likely to have greatest effects in the tropics, particularly on coral reef habitats. The elevated carbon dioxide levels and temperatures are likely to increase coral mortality through bleaching, reduce reef growth due to changing ocean chemistry and higher frequency of hurricanes resulting in shorter recovery times between impacts (Hughes *et al.*, 2003).

Coral growth and reef building processes occur only under conditions of low nutrients, warm waters >18°C, high light and stable, full salinity. Corals can be found in conditions other than these but do not form massive atoll and barrier reef structures. The range of temperatures under which reef building corals survive is wide (18-34°C) but the variance is low suggesting corals are highly adapted to live within narrow temperature tolerances.

Overheated corals expel their symbiotic microalgae (zooxanthellae) and become pale and white. If the stress is prolonged the coral will die. Temperature elevation by 1°C above the summer seasonal average is likely to cause coral mortality (Hoegh-Gulburg, 1999). Temperature rises of this magnitude and greater are associated with ENSO events which have occurred with increasing frequency in the last two decades resulting in widespread coral bleaching and mortality (Glynn, 1996). Climate change projections suggest this threshold will be chronically exceeded over the next 50 years, assuming bleaching occurs at current thresholds and the same coral and symbiont species are present (Hoegh-Gulburg, 1999). In the western Indian Ocean the probability of repeated episodes of mass bleaching similar to that observed in 1998 will increase to a 50% chance of recurrence for the warmer months within 25-35 years (Sheppard, 2003).

Thermal bleaching along with fisheries exploitation, pollution and disease are the greatest threats to coral reefs (Hughes *et al.*, 2003; Jackson *et al.*, 2001; Pandolfi *et al.*, 2003). There are no pristine coral reefs left; degradation of reefs began with fisheries exploitation at the beginning of the human era (Jackson *et al.*, 2001; Pandolfi *et al.*, 2003). In 1998 the biggest ENSO-driven bleaching event killed an estimated 16% of the world's corals, including reefs in the Indian Ocean and western Pacific Ocean (Goreau *et al.*, 2000). The degree of degradation is higher on

Caribbean reefs, it is estimated that fishing, hurricanes, bleaching and disease have resulted in a loss of 80% of hard coral cover (Gardner *et al.*, 2003). Even relatively pristine well-managed reefs such as the Great Barrier Reef, Australia have been severely degraded, hard coral cover has halved from ~40% cover in 1960-70 to the current level of 20% (Bellwood *et al.*, 2004). Overall, it has been estimated that 30% of coral reefs have been severely damaged and close to 60% may be lost by 2030 (Wilkinson, 2000).

Coral reefs form the basis of highly productive ecosystems,and the most direct uses of productivity by humanity are for food, through the exploitation of fishes, invertebrates and aquaculture of molluscs and algae and as a source of building materials, such as sand and coral rubble (Moberg & Folke, 1999). It is difficult to estimate production rates or economic value of the ecological services provided by reefs. However, as an example the fish yields of coral reefs have been observed in the range of 0.2 to 40 tkm^{-2} $year^{-1}$, and the geographic variation in yield is a result of varying population density and reef area (Dalzell, 1996). Increased bleaching, eutrophication and exploitation are likely to reduce calcification and result in the proliferation of bioeroding organisms resulting in the loss of architectural complexity of coral reefs (Bellwood *et al.*, 2004; Dulvy *et al.*, 2004; Hughes *et al.*, 2003; McClanahan, 2002). While there is considerable variation among biogeographic provinces, at a local scale the diversity and abundance of fish assemblages is linked to the cover of live hard corals and the architectural complexity of coral reefs (Chabanet *et al.*, 1997; Connell, 1978; Luckhurst & Luckhurst, 1978). Consequently climate induced change is expected to have considerable impact on the structure, function and productivity of reef fish communities.

Reefs, livelihoods and poverty

Coral reefs are a major source of ecosystem goods and services, particularly for small island developing states (Costanza *et al.*, 1997; Moberg & Folke, 1999). 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. Fish catches from shallow coastal waters in Asia are estimated to support 1 billion people (Whittingham *et al.*, 2003) and around 30 million people are involved in fisheries and aquaculture in coral reef countries (WRI, 2000). The degree of dependence of livelihoods and food security on coral reefs alone is poorly characterised, but small scale reef fishers have been identified as particularly vulnerable group (Jazairy *et al.*, 1992).

Two-thirds of coral reef nations are developing countries and a quarter of those are among the least developed countries (UNDP, 2002). High levels of poverty are found in regions with large areas of coral reef, and four regions stand out as poverty hotspots including: East Africa, South Asia, Southeast Asia and Western Caribbean (Whittingham *et al.*, 2003). However, in addition the Pacific has a very large area of coral reefs and a high proportion of population directly dependent on coral reefs and local economies. Within each of these regional hotspots there is considerable variation in reef area, population size and development and poverty indices among nations (Whittingham *et al.*, 2003). There is currently little understanding of the mechanistic links underlying high levels of poverty in coral reef nations, and consequently little understanding of the degree to which and thus importance of the role of environmental, ecological, social, economic and political factors.

Coral reef coasts but provide a diverse, productive accessible open livelihoods centred on fisheries and aquaculture resource, which are particularly attractive and important for poor and migrant people (Whittingham *et al.*, 2003). However, coral reef coasts are vulnerable to extreme meteorological events and tend to have poor infrastructure and the poor people inhabiting this area have little access to land, labour and financial resources and are particularly reliant on exploited natural resources. Consequently their income and livelihoods are highly dependent on variation and change in diversity and productivity of natural resource systems such as coral reefs. Variation and change includes natural seasonal change and shocks, such as storms, hurricanes and floods. Variation in natural resource systems is expected to increase with increased frequency and intensity of shocks, such as hurricanes and the degradation and loss of resilience of coral reefs (Bellwood *et al.*, 2004; Hughes *et al.*, 2003).

Human population growth is regarded as a major threat to the continued supply of ecosystem goods and services and the maintenance of biodiversity (Jenkins, 2003). The world's population is predicted to grow by 2-4 billion people within the next half century (Cohen, 2003). About half of the human population currently lives within the world's coastal zones and this proportion could increase to 75% by 2020 and the demand on open access natural resources is likely to increase as a consequence (IPCC, 2001). Tropical coastal and island developing countries are highly dependent upon fish, which typically comprises 30-50% of their animal protein intake (FAO, 2002). Recently, per capita supply of fish has declined markedly and the current and future sustainability of, for example, coral reef fisheries has been questioned. There is currently little understanding of the regional and national variation in sustainability of coral reef resource use (Pauly *et al.*, 2002).

Within the five reef poverty hotspots individual nations face a number of problems and threats that may negatively impact on their capacity to achieve sustained food production and poverty reduction goals. For example, they are isolated and face above average population growth, sea-level rise, increased extreme natural phenomena events, coral reef degradation and the breakdown of tradition resource management systems. Given human population growth projections and the rate of climate induced coral reef loss, there is clearly a need to explore the sensitivity, vulnerability and adaptive capacity of fisherfolk and future food production required at national, regional and global levels. There is currently no validated objective approach to identify sensitivity and vulnerability of fisherfolk in coral reef countries to climate change and human population growth, or to measure the degree of adaptive capacity to cope with projected changes. The work synthesised in the report provides a first step towards rectifying this knowledge gap.

The aim of this case-study was to develop a simple statistical model to describe the link between the per capita fish consumption of fisherfolk and the potential supply and demand of reef resources at national scales.

Methods

The approach was to compile national level statistics and use each nation as a datum in a comparative analysis.

Data sources

We assumed that the supply of reef resources, in this case fish production, is a function of national coral reef area (Jennings & Polunin, 1995a). Coral reef area has been calculated to the nearest 100 km^2 for each coral reef country from remotely sensed maps of coral reefs (Spalding *et al.*, 2001). We assumed that the human population density of each nation per unit of reef area was a proxy for demand for fish as food. National human population estimates and population projections are available from the United Nations Population Division. From these measures we generated an index expressed as the human population size km^{-2} of coral reef.

Model building and future scenarios

Previous island scale ecological work suggests that fish abundance, biomass and diversity and coral reef health is lower at islands with high population densities relative to the area or linear extent of coral reef or coastline, assuming all other factors are equal and in the absence of confounding factors such as poaching (Bellwood *et al.*, 2003; Dulvy *et al.*, 2004a; Dulvy *et al.*, 2004b; Jennings & Polunin, 1995a, 1996a, b, 1997; Pollnac *et al.*, 2000). This provided the motivation to test whether this decline in natural resource condition along gradient of human population density per unit of coral reef would be detectable as a reduction in the amount of fish consumed per head of population. Per capita fish consumption is measured as the total fish consumed in kilograms year^{-1} person^{-1}. This statistic is derived from the supply / utilisation accounts of the Food and Agricultural Organisation of the UN which compiles stocks, exports, animal feed, seed, processing for food and non-food purposes, waste (or losses), and lastly, as food available to the population, where appropriate. We built a linear model of the relationship between human population density and per capita fish consumption for island and island and continental nations combined only.

There are three broad human population growth scenarios and for the sake of generality we have only presented results of the 'medium-variant' projection for the years 2015, 2025 and 2050 (Cohen, 2003). The links among climate change, ENSO frequency and bleaching-related coral mortality are poorly understood and it is not yet possible to forecast the future extent of coral reef at national scales. However, we know that coral cover has declined by 0.5% to 1.5 % year^{-1} on regional scales, so we have arbitrarily chosen a range of values of within a similar order of magnitude – 5%, 10% and 15% loss of coral reef applied over the first 15 years of the projection (2000 to 2015). These rates are equivalent to annual rates of loss of 0.33%, 0.66% and 1% year^{-1} respectively. This assumes that hard corals are the important functional unit on coral reefs and the loss of hard corals is proportional to the loss of total coral reef area, where coral reef is as defined in the World Atlas of Coral Reefs (Spalding *et al.*, 2001). We consider a case of no coral loss and no population growth as a "no change" scenario. The future scenarios use the current model to estimate the average future per capita fish consumption for the "no change", 5, 10 and 15% coral reef area loss with medium-variant projected human population growth. We compare the sensitivity of modelled future per capita fish consumption to coral reef loss and human population growth between 2000 and 2015.

Results

Per capita fish consumption (kilograms consumed per person each year) was significantly negatively correlated with human population density (people km^{-2} coral reef) (r^2= 0.51, F = 44.9, P<0.0001; Figure 5.8, overleaf). Per capita fish consumption is highest in lightly populated Pacific nations (e.g. Palau, Fiji) and lower in heavily populated Atlantic and Indian Ocean nations (e.g. Cuba & Philippines). This significant pattern also holds, albeit more weakly, if continental coral reef nations are also included in the model (r^2= 0.29, F = 36.2, P<0.0001).

The negative relationship suggests that there is a finite amount of fish available for human consumption per unit area of reef and represents a fundamental constraint on fish production and consequently on per capita consumption. The increase in harvesting pressure associated with higher human population densities is analogous to a resource depletion experiment. Hence the maximum amount of fish available for consumption from an unpopulated and un-harvested reef can be estimated by extrapolating this relationship backwards. For a value of 1 person kilometre^{-2} reef the theoretical per capita fish consumption would equal 152 kg per person per year. However the units cancel such that,

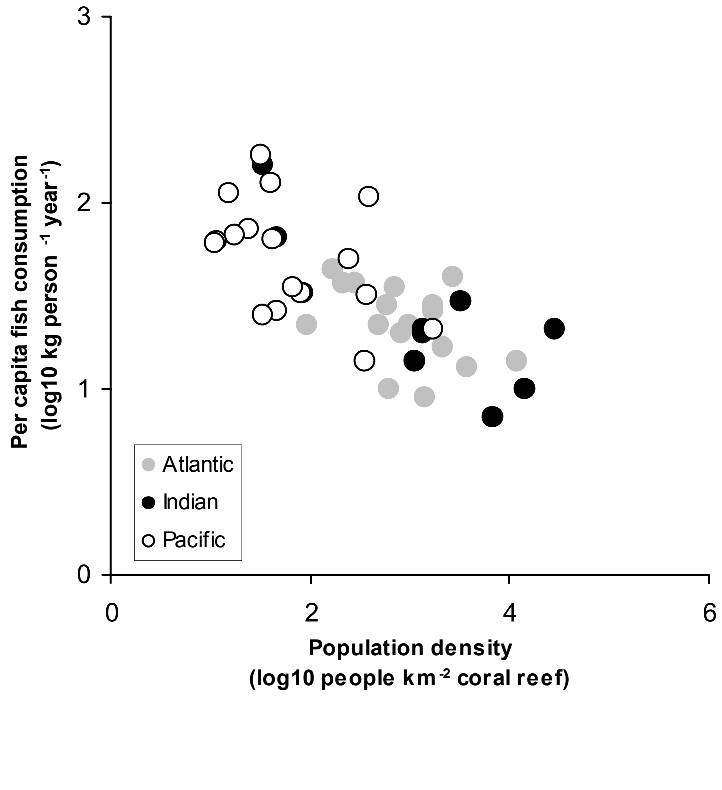
1 person km^{-2} reef produces 152 kg fish for consumption person^{-1} year^{-1}

becomes;

1 km^{-2} coral reef produces 152 kg of fish for consumption year^{-1}

This appears to be the maximum rate of fish production that is catchable and available for human consumption for the average square kilometre of coral reef of island countries.

Figure 5.8 Relationship between human population density and per capita fish consumption for 44 tropical island coral reef countries in three oceans



The fish available for consumption per person halves with each order of magnitude increase in population density. As a result, islands with population densities around 100 people km^{-2} coral reef (Solomon Is., Fiji Is., Bahamas) would be expected to have half the fish available for consumption (44 kg person^{-1} yr^{-1}) compared to islands (Marshall Is. Tuvalu, Niue) with a tenth of the population density (82 kg person^{-1} yr^{-1}). Most countries, 39 out of 44, consume more than half of the available production each year. The only countries consuming less than 50% of the available production include: Maldives, Palau, Tokelau, Kiribati and Tuvalu.

There is considerable amount of unexplained variation around this relationship; only half of the variance is explained by human population density. Consequently two island nations exhibiting similar population densities can have widely differing rates of per capita fish consumption. Four pairs of island nations can be readily compared. Papua New Guinea and Palau have similar population densities and widely differing consumption rates - 14 and 108 kg $person^{-1}$ yr^{-1} respectively (Table 5.5). Another example would be the Maldives and New Caledonia where population density is identical and the observed values are 160 and 25 kg $person^{-1}$ yr^{-1} respectively. Such comparisons raise questions as to why consumption is below the expected in Papua New Guinea, New Caledonia, Vanuatu and Cuba and above that expected in island countries with similar population densities such as the Maldives, Seychelles, Palau and Philippines (Table 5.5). Additionally there are a number of island nations with similar densities and patterns of consumptions (Table 5.5).

Both loss of coral reef area and human population growth have considerable impacts on estimated future per capita fish consumption as a result of finite fish production per unit area coral reef (Figure 5.9). Population growth alone without loss of coral area is predicted to result in decline in per capita fish consumption of 13.2% by 2015 and almost 20% by 2050. This is equivalent to a decline in per capita fish consumption of 0.3-0.9% $year^{-1}$, the higher rates of decline occur up to 2015 and the lower decline rate applies up to 2050. The relative effect of projected human population growth and loss of coral reef area on per capita fish consumption are compared from 2000 – 2015 (Table 5.6). Projected human population growth is predicted to reduce per capita fish consumption by 0.88% $year^{-1}$ and the loss of coral reef area is predicted to reduce per capita fish consumption by 0.1-0.3% $year^{-1}$ (Table 5.6). The highest rate of reduction in per capita fish consumption is based on a loss of coral reef area of 1% $year^{-1}$.

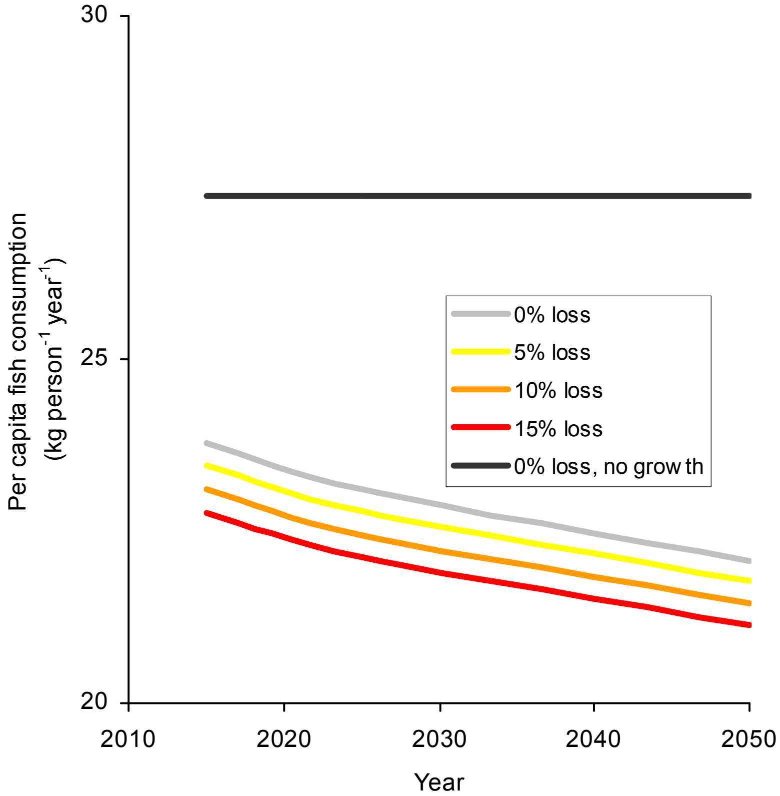
Table 5.5 Comparison of human population density, per capita fish consumption and predicted per capita fish consumption for pairs of nations with similar population densities and (A) dissimilar fish consumption patterns, and (B) similar fish consumption rates

Paired comparison	**Human population density** (people^{-1} km^{-2} coral reef)	Per capita fish consumption (kg person^{-1} yr^{-1})	Predicted per capita fish consumption (kg person^{-1} yr^{-1})	Residual per capita fish consumption (kg person^{-1} yr^{-1})
(A) Dissimilar consumption patterns				
New Caledonia	34	25	59	-34
Maldives	34	160	59	101
Vanuatu	46	26	54.2	-28.2
Seychelles	47	65	53.9	11.1
Papua New Guinea	356	14	31.3	-17.3
Palau	380	108	30.7	77.3
Cuba	3689	13	16.7	-3.7
Philippines	3240	30	17.3	12.7
(B) Similar consumption patterns				
Solomon Islands	81	33	46.6	-13.6
Fiji Islands	83	33	46.3	-13.3
Comoros Islands	1344	20	21.9	-1.9
Mauritius Island	1355	21	21.8	-0.8
Guadeloupe	1704	28	20.5	-7.5
Martinique	1729	26	20.4	-5.6

Table 5.6 The effect of human population growth (medium variant projection) and varying rates of coral reef loss on estimated per capita fish consumption between 2000 and 2015 averaged over 44 coral island countries

Model	Estimated average per capita fish consumption (kg $year^{-1}$)	Reduction in average per capita fish consumption (%)	Reduction in average per capita fish consumption (% $year^{-1}$)	
0% coral loss, no population growth	27.4			
0% loss	23.8	13.2	human population growth only =	0.88
5% loss	23.5	1.4	0.33% yr^{-1} coral loss only =	0.1
10% loss	23.1	2.8	0.66% yr^{-1} coral loss only =	0.2
15% loss	22.8	4.3	1% yr^{-1} coral loss only =	0.3

Figure 5.9 Change in future projected per capita fish consumption averaged over 44 tropical island coral reef countries for four combinations of coral reef loss (0%, 5%, 10%, 15%) and with projected human population growth (medium variant scenario). The black line represents the "no change" scenario with no change in coral cover and no further human population growth



Discussion

This analysis suggests that ecological and demographic models of the variation in per capita fish consumption among coral island countries may provide a tool to explore the effects of climate change and human population growth on fisheries dependent livelihoods. Per capita fish consumption appears to be constrained in two ways. First there is a fundamental upper limit to the per unit area production of fish for consumption by island country coral reefs. Second, if this finite amount of fish production is thought of as a pie, then this pie is sliced increasingly finely at greater human population densities. Each order of magnitude increase in population density results in a halving of per capita fish consumption. High population densities (relative to coral reef area) are associated with lowered per capita fish consumption. The fundamental upper limit of reef fish production available for consumption, combined with increasing population densities represents two fundamental ecological constraints to fisheries dependent livelihoods and food security of the poorest people on coral reef island nations. While the former constraint (finite fish production) was known, the second important constraining effect of human population density had not been recognised.

The alternative explanation for low per capita fish consumption rate in nations with high population densities is that such nations may have larger land areas and hence access to other sources of meat and protein, e.g. through agriculture, resulting in a lower reliance upon fish. Clearly the issues of land area and other alternative protein sources need to be explored in order to differentiate between these explanations. This comparative approach provides an opportunity to identify why such differences and similarities may exist across countries and allow a test of this alternative hypothesis. Questions could be asked related to differences in geography, other fisheries, aquaculture, agriculture, trade, even incorporating technological, social, economic and political factors. This approach can be used in two ways: (1) the additional variance explained by other geographical or ecological factors can be assessed and if significant can be incorporated to develop better predictive models of fish consumption which can be used to explore the consequences of population growth and climate change induced habitat loss on per capita fish consumption, and (2) the additional variance explained by social, economic and political factors can be explored. Understanding the relative importance of additional explanatory variables can be used to understand sensitivity and adaptive capacity in an objective manner. Consequently the approach can be used to identify general mitigation strategies to deal with the effects of human population growth and coral reef loss due to climate change.

With nation-scale correlations causality cannot be easily inferred, however this relationship is consistent with smaller-scale ecological and socio-economic field studies of fishing behaviour, fish consumption and sustainability of reef fisheries (Jennings & Lock, 1996; Jennings & Polunin, 1995a, b, 1996b, c; Polunin & Jennings, 1998). The observed yield of coral reefs have varied between 0.2 to 40 t km^{-2} $year^{-1}$ but the emerging consensus is that 5 t km^{-2} $year^{-1}$ represents the upper limit of sustainable exploitation (Dalzell, 1996; Dalzell *et al.*, 1996; Jennings & Polunin, 1995a; Warren-Rhodes *et al.*, 2003). The estimate presented here is not fish yield *per se*, but of fish consumed and the amount of fish consumed is at least 30% less than yield due to gutting (Jennings & Polunin, 1995a). This results in an estimate of 0.22 t km^{-2} $year^{-1}$, which is similar to the lowest observed yields. This estimate assumes all fish caught are consumed and thus does not account for any discarding. However, a key source of variation in previous estimates of fish yield from coral reefs is the definition of fishable habitat and the maximum depth fished (Dalzell, 1996). The definition of coral reef habitat used here is wider than that used in previous studies and measured at a coarser scale (1 km^2 grid square) and encompasses all depths within the habitat definition. This coral reef habitat definition may be coarser but is more useful as it is comparable across countries. This analysis assumes that all fish consumed are derived from coral reef habitats; this is certainly not the case for a number of nations, e.g. the inhabitants of the Maldives have a preference for oceanic tuna rather than reef fish, and in Fiji and other Pacific Islands large quantities of imported tinned fish are consumed. While mindful of such important caveats we can use this statistical relationship to explore the consequences of human population growth and climate change on per capita fish consumption.

This preliminary modelling suggests the loss of coral reef at annual rates similar to that historically observed may have an impact on per capita fish consumption. The effect of reef loss is smaller, approximately one third, than the effect of human population growth on projected per capita fish consumption rates. The results presented here are averaged over all the 44 countries studied, and assume the future loss of coral is spread evenly among the countries. There is scope to use climate modelling and coral reef loss estimates and individual human population projections to explore the relative vulnerability of individual countries.

This analysis demonstrates two fundamental constraints to fish consumption and identifies a framework by which the sensitivity, vulnerability and adaptive capacity of coral island nations and their fisherfolk to climate change and human population growth can be explored in an objective and strategic manner. This framework can be used to identify similarities and differences among countries and can thus be used to identify potential mitigation options.

5.4.2 African Lakes

Introduction

Africa's fish consumption needs are largely met from the continent's capture fisheries. Aquaculture production and imports from other continents are relatively small; the future productivity of its coastal zones and inland waters therefore represent a key source of food and livelihood opportunity. Egypt, Tanzania and Uganda are among the top ten freshwater fish producers in the world, and Africa supports over 2.6 million fisherfolk - 7 % of the world's total and second only to Asia. The West African Region has among the highest proportionate reliance of fish as a source of dietary animal protein (FAO, 2004). Inland fisheries are particularly important sources of food and livelihood for the poor, being generally more accessible than marine resources.

Our vulnerability analysis (Section 5.3) has demonstrated that most of the most vulnerable countries (most exposed, most sensitive terms of economic and nutritional dependency and least able to adapt) are in Africa. There are therefore good reasons to pay special attention to the potential impacts of climate change on Africa's inland fisheries. The work outlined in this section provides only a preliminary introduction to some of the potential issues; there is a clear need for a more in-depth regional synthesis.

Climate variation and its impacts in Africa

There is now an extensive literature on the effects of and interactions between African climate variability and African environments and human societies. Much of this literature concerns drought and its effects on farming systems (e.g. Glantz, 1987; Akong'a et al., 1988; Bohle et al., 1994). In addition to the climate oriented work, there is also a huge literature of conceptual and empirical studies of responses and coping strategies, much of which appears in development and/or disasters or risk arenas (e.g. Corbett, 1988). This extends into a large literature on famine and food security including Sen's (1981) work on entitlements, case studies of particular famines (Rahmato, 1991), governmental and NGO responses (Drèze and Sen, 1989) and interactions with non-climatic factors (De Waal, 1997).

Because of the obvious links between the success of rain-fed farming and rainfall variability, most regional studies of climate variability have looked at patterns of rainfall variability (Conway et al., 2005). Direct studies to examine regional evidence of global warming are less frequent but there have been a few notable publications. For temperature, Hulme et al. (2001) found an African mean warming of about 0.50°C/century. King'uyu et al. (2000) analysed 71 long daily maximum and minimum temperature records for the Horn, Eastern and Southern Africa. They identified a significant, but spatially non-uniform, rise in minimum temperatures at several locations, but with many coastal areas and stations near large water bodies showing a significant decrease. The northern part of their study region generally exhibited cooling in maximum temperatures.

Recent evidence from Lake Tanganyika (Verburg et al. 2003) highlights the ecological consequences of a century of observed regional warming in the lake. They associate warming with a sharpened density gradient which has slowed vertical mixing and reduced primary productivity. Further warming is hypothesised to continue these trends. These findings for Lake Tanganyika are supported by O'Reilly et al. (2003) who show that the rise in surface-water temperature has increased the stability of the water column. This, combined with lower wind speeds, has reduced mixing in the lake and primary productivity may have decreased by about 20 per cent accounting for a roughly 30 per cent decrease in fish yields.

Detailed studies of long term climate and ecosystem behaviour are severely constrained by availability and reliability of biophysical observations in much of Africa. The study by O'Reilly et al. (2003) was recently questioned about their use and interpretation of observed records of temperature and wind speed (Eschenbach 2004; O'Reilly et al. 2004), particularly on the basis of data quality (homogeneity of the climate records). Questions about data coverage and reliability are likely to be important in research on longer term climate or environmental changes in many parts of Africa. Developing reliable records with detailed histories should form part of the activities of African meteorological services with a view to developing a rigorous set of climate (and other environmental) indicators that could serve as a basis for climate change detection, for example as has been done for the UK (Cannell et al. 1999).

Future climate change in Africa

In the IPCC's earlier assessment reports there was no attempt to review comprehensively the regional characteristics of climate change scenarios from different GCMs. Hulme (1994) contains the first continent wide presentation of GCM scenarios for Africa. In the intervening years up to the Third Assessment Report of the IPCC numerous case studies of climate change impacts and adaptation were published but few with a full continental perspective. Working Group I of the TAR (*The Scientific Basis of Climate Change*) contains a detailed review of regional temperature and rainfall changes projected by nine state-of-the-art GCMs (IPCC 2001b, Chapter 10). This presents climate changes in terms of the inter-climate model consistency (i.e. the agreement between models) for different regions of the world. Table 5.7 summarises the results for the four regions identified for Africa in two seasons, December to February (DJF) and June to August (JJA) with high GHG emissions and low GHG emissions. Warming is projected to occur more rapidly than the global average in the Sahara region and West (DJF only) and Southern Africa (JJA only). Warming occurs in all other regions and in both seasons but with less consistency in rate between GCMs.

For future rainfall patterns the results are less consistent between GCMs (Table 5.7 lower part). The main rainy seasons in Southern Africa (DJF) and parts of West Africa (JJA) show inconsistent changes, as does the JJA season in East Africa (important to large parts of Ethiopia and Sudan). The clearest signal is the large increase in JJA in the Sahara where rainfall amounts are extremely low and large percent increases would only amount to small absolute changes.

Climate change impacts

This synthesis of the general work on climate change impacts and Africa uses the IPCC TAR *'Impacts, Adaptation, and Vulnerability'* (IPCC, 2001b) as the best summary of this huge literature. Box 5.4 presents the main findings from the Summary for Policymakers and Box 5.5 presents the findings from the regional chapter on Africa. The rationale for most of the studies reviewed in IPCC (2001a) comes from a problem-centred approach to assessing the impacts of climate change often along sectoral lines and following methods outlined in the climate literature (e.g. Carter et al. 1994) using climate change scenarios and process-based impacts models with little incorporation of adaptation. The report of Working Group II (IPCC 2001a) also contains sectoral reviews of impacts; hydrology and water resources, agriculture and food security, terrestrial and freshwater ecosystems, coastal zones and marine ecosystems, human health, human settlements, energy and industry and insurance and other financial services.

There have been increasing attempts, especially since the late 1990s, to take a more integrated approach, to consider adaptation as a more dynamic and important process and to use insights from existing climate-society interactions to inform interpretations of impacts and their implications. Examples include Downing et al. (1997) and the Climate Research journal special issue *Anthropological Perspectives and Policy Implications of Climate Change Research* (Magistro et al. 2001) which uses detailed case studies of risk management, livelihood impacts and climate variability in pastoralist and farming communities. A good example of the interactions between research in climate variability and more mainstream development research and activities is the special issue of 'Global Environmental Change' on *The African Sahel 25 Years After the Great Drought*. Box 5.5 presents the key summary of findings on adaptation in Africa also taken from IPCC TAR *'Impacts, Adaptation, and Vulnerability'* (IPCC, 2001b).

Table 5.7 A summary of inter-climate model consistency regarding future rainfall change for Africa caused by greenhouse gas emissions.

Region	DECEMBER TO JANUARY		JUNE TO AUGUST	
	High emissions scenario	Low emissions scenario	High emissions scenario	Low emissions scenario
Temperature changes				
Sahara	Greater than average	Greater than average	Greater than average	Greater than average
West Africa	Greater than average	Greater than average	Inconsistent warming	Inconsistent warming
East Africa	Inconsistent warming	Inconsistent warming	Inconsistent warming	Inconsistent warming
Southern Africa	Inconsistent warming	Inconsistent warming	Greater than average	Greater than average
Rainfall changes				
Sahara	Inconsistent	Inconsistent	Large increase	Large increase
West Africa	Small increase	Small increase	No change	Inconsistent
East Africa	Small increase	Small increase	Inconsistent	Inconsistent
Southern Africa	Inconsistent	Inconsistent	Small decrease	Small decrease

Notes:

Source: Adapted from IPCC (2001b, Box 10.1, Figure 2).

IPCC (2001b) definitions of consistency: seven out of nine GCMs must show a consistent change for results to be classified in agreement

For temperature: rate of warming with respect to the global average which spans 1.2 to 4.5°C for emissions scenario A2 and 0.9 to 3.4°C for B2.

For rainfall: large increase (decrease) - agreement on increase with average change greater than +/- 20%. Small increase (decrease) - agreement on increase with average change between +/- 5 and +/- 20%. No change - agreement with average change between -5 and +5%.

Box 5.4 Emergent findings from IPCC 2001 WG II

- Recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems
- There are preliminary indications that some human systems have been affected by recent increases in floods and droughts
- Natural systems are vulnerable to climate change, and some will be irreversibly damaged
- Many human systems are sensitive to climate change, and some are vulnerable
- Projected changes in climate extremes could have major consequences
- The potential for large-scale and possibly irreversible impacts poses risks that have yet to be reliably quantified
- Adaptation is a necessary strategy at all scales to complement climate change mitigation efforts
- Those with the least resources have the least capacity to adapt and are the most vulnerable
- Adaptation, sustainable development, and enhancement of equity can be

Source: section headings for section 2 WG II Summary for policymakers, pages 2-7

Box 5.5 *'Vulnerability varies across regions'* IPCC 2001 WG II summary findings on adaptive capacity, vulnerability, and key concerns for Africa

- Adaptive capacity of human systems in Africa is low due to lack of economic resources and technology, and vulnerability high as a result of heavy reliance on rain-fed agriculture , frequent droughts and floods, and poverty
- Grain yields are projected to decrease for many scenarios, diminishing food security, particularly in small food importing countries (medium to high confidence)
- Major rivers of Africa are highly sensitive to climate variation; average runoff and water availability would decrease in Mediterranean and southern countries of Africa (medium confidence)
- Extension of ranges of infectious disease vectors would adversely affect human health in Africa (medium confidence)
- Desertification would be exacerbated by reductions in average annual rainfall, runoff, and soil moisture, especially in southern, North and West Africa (medium confidence)
- Increases in droughts, floods, and other extreme events would add to stresses on water resources, food security, human health, and infrastructures, and would constrain development in Africa (high confidence)
- Significant extinctions of plant and animal species are projected and would impact rural livelihoods, tourism, and genetic resources (medium confidence)
- Coastal settlements in, for example, the Gulf of Guinea, Senegal, Gambia, Egypt, and along the East-Southern African coast would be adversely impacted by sea-level rise through coastal inundation and coastal erosion (high confidence)

Source: IPCC 2001 WG II, Table SPM-2, page 13

There is now a rapidly growing literature that examines the interactions between climate change and development. Much of this literature originates from an interest in vulnerability and adaptation in relation to climate change and exposure to climatic extremes (Downing et al. 1997; Adger, 1999; IPCC 2001a). In addition, there is of course a vast array of development research which includes an explicit (sometimes) or implicit (often) climate dimension, primarily in the form of livelihood strategies exposed to climate shocks (floods and drought), food security and disaster and longer term development assistance. Studies range from macro-economic analyses of the impact of drought on African economies (Benson and Clay 1998) to more detailed analyses of local strategies dealing with episodic and longer term shifts in rainfall patterns (Mortimore and Adams 2001) and flooding events (Few 2003). Research on non-equilibrium behaviour in African rangeland and lake systems is also highly relevant in relation to climate change (Scoones 1995; Sarch & Allison, 2000; Jul Larsen et al., 2003). Glantz (1992) and Adger et al. (2003) highlight the importance of using and improving our understanding of the existing linkages between climate variability and biophysical and social systems as a basis for exploring the effects of future changes in climate.

Lake Level fluctuations and livelihoods in Southern Africa – the case of Lake Chilwa, Malawi

<u>Introduction</u>

The twelve countries of the SADC region[3] are estimated to have produced, on average, approximately 620 000 tonnes of fish per year from inland waters during the period 1991-1995 (Jul Larsen et al., 2003, p18). Much of this production comes from fisheries for small pelagic species (kapenta, dagaa, chisense) and has fuelled an increase of 160% over the last 20 years in the estimated number of fishermen working on the regions' main waterbodies. This increase is, however, highly variable, with some waterbodies (e.g. Lake Bangweulu in Zambia) showing a 24% decrease in the number of fishers during the same period. The large increases in production and effort on some water bodies and decreases on others can be explained by the mobility of the fisherfolk as a response to fluctuating livelihood opportunities driven by a combination of 'boom and bust' type exploitation patterns and climate-driven fluctuations in the productivity of both farming and fishing environments.

It is now well-established that fishing livelihoods in the region are adapted to change, and that responses to climate change and variability are a significant determinant of the occupationally and geographically mobile livelihood strategies adopted by the majority of small-scale fisherfolk thoughout Africa's inland waters (e.g. Geheb & Binns, 1997; Sarch & Allison, 2000; Sarch & Birkett, 2000; Allison et al., 2001; Jul-Larsen et al., 2003). Indeed, the climate-sensitivity and non-equilibrial nature of the fishery production systems has led some of us to question the need for fisheries management based on 'sustainable yield' objectives, whether implemented through government licensing schemes or community-based management (Sarch & Allison, 2000; Jul-Larsen et al., 2003). At global level, the debate (initiated by Larkin, 1977) about the validity and role of stable yield objectives for fisheries management in the face of irreducible variability and uncertainty continues (e.g. Flaaten et al., 1998; Stokes et al., 1999).

Understanding the responses of ecosystems, people and their institutions (households, communities, cultures) to past climate-driven changes can provide important information to policy makers on existing adaptive strategies that might be built upon to support vulnerable

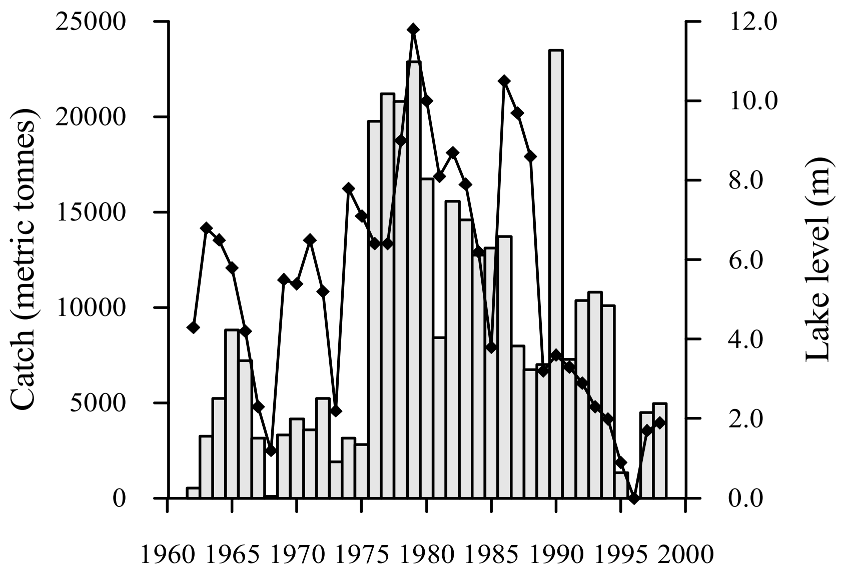
[3] Angola, Botswana, Democratic Republic of Congo, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe

peoples' livelihoods. While the synthesis of existing information and new studies are providing important contributions to this aim, many are based on piecing together fragmented historical data and relying on recall surveys to understand adaptive responses and coping strategies in the recent past. There is a paucity of longer-term studies examining adaptation using comparable methods and data, or of re-sampling of the same area at widely spaced time intervals to assess change. One of the few such datasets is that for Lake Chilwa in Southern Malawi, where instructive comparisons can be made between recent livelihood surveys (Allison and Mvula, 2002) and a multi-disciplinary survey of the Lake Chilwa basin, conducted by researchers at Chancellor College during the 1960s (Kalk, 1970; Kalk et al., 1979).

<u>Lake Chilwa</u>

Africa's shallow lakes are among the most productive but variable fishery ecosystems in the tropics. The lake has recently fluctuated around 1850 km^2 including both open-water and wetland areas; it is less than 3 m deep and is subject to extreme fluctuations, including complete desiccation. In good years, fish catches can be as high as 25 000 tonnes (fishery statistics are rather uncertain and vary between sources) and more than 10 000 people are engaged in fishing activities. There was a major increase in fishing effort around the early 1970s, as the region became better integrated into the market economy. Minor recessions in lake level, sufficient to reduce fishing for one or two years, can be expected every six years or so (see Figure 5.10). Major recessions which will interfere with fishing in the open lake for 3-5 years can be expected every 60-70 years, with a possibility of an intermediate recession in 30-40 years (Lancaster, 1979). The last drying episode covered the period from late 1994 to 1996, when fishing ceased altogether. Fishing operations started again in April 1997 (GOM, 1999).

Figure 5.10. Catch fluctuations (shaded bars) and lake level variations in the shallow Lake Chilwa, Malawi 1962-1998.



Note that the lake gauging system was changed in 1989 and the lake level measurements from this period onwards may not be directly comparable with those in previous years, and have a lower apparent amplitude of fluctuation

Livelihood strategies and change, 1966 - 2001

Livelihoods research conducted in two lakeshore villages, in 2001 (Allison & Mvula, 2002) revealed that, in order to survive and benefit from fluctuations in the lake level, households adopted one of two major strategies, according to their origins and degree of access to land: they were either migrants, heavily dependent on fishing and fish-trading (contributing >80% of their household incomes) or residents engaged in various mixes of farming, trading, wage-labour, self-employment and fishing (with fishing and fish trading typically making up 30 to 50% of total household income). Both these strategies allowed for a degree of adaptation to the variable environment, but both are under threat from various governance reforms that aim to improve livelihoods, but do not incorporate climate-adaptive responses in their planning. These include various land-tenure reform proposals and the introduction of community-based management that would restrict access by migrants. Surprisingly, household incomes among migrant fisherfolk tended to be higher than those for resident farmer-fishers – a finding replicated in other studies in Eastern and Southern Africa (Allison, 2005). The trade-off between these higher cash incomes may be in increased vulnerability and marginalisation (a 'faustian bargain' – Wood, 2004).

The comparison between livelihood strategies and options in the late 1960s and the early 2000s highlights changes in production options, livelihood strategies and outcomes that point to a likely reduction in the capacity of people living around the lake shore basin – and the regional economy - to adapt to future climate variability and change.

The most striking changes to the productive economy of the area are the decline of livestock, the growth in rice production and the apparent change in scale and ownership structure in the fishery. In 1969, there were 34,818 cattle grazing on the Chilwa plain, with most farmer-fishers owning some large livestock. In 1999, official statistics indicate there were less than 3 000 cattle in Zomba district as a whole, although the same report claims that there are an average of 22 cattle per farm family in Zomba District (Kishindo, 2001 p 33). This does not seem likely to apply to the Lake Chilwa shoreline and wetlands (one of the major grazing areas in Zomba District). The current figures for livestock-keeping in lakeshore villages from the livelihoods surveys (averaging 0.43 Cattle Equivalent Units[4]) are amongst the lowest recorded in agricultural surveys in sub-Saharan Africa (Ellis & Freeman, 2004).

In 1969, rice and cotton production for the whole Chilwa plain were of the order of 1,600 tonnes each. Between 1989 and 1999, rice production from Zomba district alone fluctuated between about 5 and 15 000 tonnes (Kishindo, 2001). After disappearance in the early 1990s, cotton production has attained similar levels to that in the 1960s over the last 5 years. Fifty to seventy per cent of the land on the Lake Chilwa plain was under crops in 1969; this apparently remains the same for Zomba District (Kishindo, 2001). The Lake Chilwa area has been densely populated for at least the last 40 years, but land appears to be still available, partly because the constantly fluctuating lake level periodically changes the area available for cultivation.

Diversified, adaptable and mobile rural livelihoods are characteristic of this unstable production environment. A sample of 528 fishermen interviewed in 1969 showed that most were part-time farmer-fishers, 93 per cent owned their own boats and 61 per cent gained some income by hiring out their boats when not themselves using them. In 1966, there were also 2 000 migrant fishermen living in the marshes in Kasupe district alone, this from a total of 6,444 fishermen, ancillary workers and their families living within the Lake environs – i.e. on reed rafts, islands and in the wetlands. On Chisi Island (83 km^2) there were 11 villages

[4] Livestock are commonly scaled to 'cattle equivalent units' based on their relative market values, allowing comparison of livestock holdings among people with mixed 'herds' of cattle, goats, sheep, pigs and poultry.

with 2015 people. Men outnumbered women by 15 to 1 – most of them were migrant fishermen. By 1968, when the lake had dried out, the population of Chisi Island had fallen to 779 persons. All the temporary migrants had left, and 228 resident men had left to find alternative employment. At Kachulu fish landing (near our 2001 study site at Sauka) population fell from 800 in 1966 to 186 in 1968.

Agnew (1979) & Agnew & Chipeta (1979) summarise the short-term choices of fishermen during the lake-drying period of 1967-68 as: 1) fishing on a very much reduced scale in the remaining swamps, streams and lagoons in the Chilwa catchment, 2) transfer to nearby Lakes Malombe, Malawi or Chiuta, 3) increasing the cultivation of rice, cotton cassava and vegetables 4) a switch over to commercial handicrafts such as plaiting carpets, 5) spending considerable time trapping birds and digging for rodents or 6) seeking employment elsewhere. These responses varied according to income status, asset profiles, ethnicity and time of residence in the area. In the drying episode of 1968, around 200 fishermen migrated to nearby Lake Malombe, and others moved to Lake Malawi. These were among the richest fishermen, whose investment in fishing-related assets meant that they could not simply cease fishing, as could those with less stake in this source of livelihood. Since the introduction of community-based management in Lake Malombe and Southern Lake Malawi (Sholtz *et al,* 1998, Chirwa, 1998), the option to move fishing operations between lakes is constrained, but this was still a major response to the drought of 1995/6. Conversely, the response by people in Sauka village to the heavy rains and floods of 2000/2001, resulting in low agricultural harvests, was a shift into fishing by lakeshore communities.

The relative wealth differentials between farmers and fisherfolk also seem to have been maintained over the last four decades. Specialist fishing households tended to have higher incomes than farming families in our 2001 survey (Allison & Mvula, 2002). Most of the 1200 fishermen interviewed by Chipeta (in Kalk, 1970, p46-47) in 1966 were small-scale semi-subsistence fishermen, making their own canoes and using nylon nets, consuming part of the catch and making use of only one relative to help them. Despite this small scale of operation, between 1963 and 1969, fishermen's incomes were several times those of the average small-holder farmer. Fleet ownership structure is not known at present, but the sharp differentiation in income levels between boat/gear owners and others engaged in the fishery (Allison & Mvula, 2002), plus the observation of larger 'plank boat' units, suggests that ownership of fishing assets is now more polarised, with small numbers of wealthier individuals owning two or more boats and several types of fishing gear.

The linkages with other rural businesses were also well established: "Fishing, which is done exclusively by men and is a part-time occupation for many, has stimulated on the shores of Lake Chilwa a number of economic ventures: fish processing and trading, hawking, beer brewing by women, shops and bars.", The successful fishermen in the 1960s had larger gardens and produced more cash crops than other fishermen; this remains the case today, particularly as fishing gear owners are among the few people who can afford agricultural inputs now that fertiliser subsidies have been withdrawn under structural adjustment policies.

Thus, although the fisheries of Lake Chilwa offer an economically unstable environment, determined by the seasonal and long-term fluctuations in lake level, at high production periods the fisheries permit readily earned cash. In good years, Lake Chilwa supplies almost half the total fish production in Malawi. Management that constrains access to fish in productive periods constrains income-generating opportunities, denies people access to subsistence and serves no conservation purpose in a lake where the sustainable yield concept is obviously untenable. And yet, despite wide-spread acceptance that fisheries management, in its traditional guise of stock conservation measures, is inappropriate, there have been recent measures to introduce fishery regulations to stabilise yields and conserve stocks. This goes counter to Kalk's suggestion that uncertainty about lake levels suggests that development effort be focused on agriculture, rather than fisheries.

The repercussions of recession in Lake Chilwa waters and consequent decline of fishing are much wider than on fishing alone. The whole of the Chilwa plains and lake must be seen as an economic network. Not only are there links between fishing and various ancillary services, but also complementary flows of income between fishing and farming. The "integrated small-scale economy of farming, fishing and cattle-rearing" of the 1960s (Kalk, 1979; p15) has now changed to one in which cattle-rearing has all but disappeared as a saving and livelihood option, potentially decreasing the resilience of the overall livelihood system.

Sectoral concerns for the sustainability of individual natural resource systems have prevailed, even when it is known that notions of resource sustainability are questionable. "The Chilwa fishes are clearly well fitted to persist in the unpredictable Chilwa ecosystem, provided the refugium of swamps and streams is maintained", according to Moss, (1979, p411) who also cautions that more dangerous than overfishing in this resilient system were threats to the swamps through reclamation for agriculture or perhaps as irrigation reservoirs, siltation through changes in catchment land-management, and pesticides. It is these threats that have led to recent interest in environmental management in the Chilwa wetland, and its designation as a Ramsar site. (Environmental Affairs Department, EAD 2000).

The EAD report reiterates the perceived resilience of the system. However, in an analysis of fisheries issues (EAD, 2000, Table 5.2), the report highlights "Ignorance, Poverty, Corruption, Migratory fishermen and Lack of Resources" as barriers to sustainable utilization of fishery resources, and recommends the implementation of "community-based natural resource management for the benefit of the local people". There is clearly some difficulty in accepting that migration may be a legitimate and sustainable strategy to maximize benefits from a fluctuating resource, a factor that needs to be taken into account in the design of any community-based management scheme. Around Lake Chilwa, there are large-scale shifts from fishing to farming, pastoralism and other occupations when the lake dries out (and back to fishing when it refills). Such strategies highlight the importance of enhancing or maintaining the flexibility of lake-shore livelihoods rather than constraining it with fixed fisheries production quotas, seasons or areas. Adapting successfully to future climate change may depend on reversing some of the current policy directions and supporting adaptive strategies that have withstood and adapted to at least 40 years of change.

Lake Tanganyika's pelagic fisheries: a link to El Niño and regional evidence of the impact of global warming?

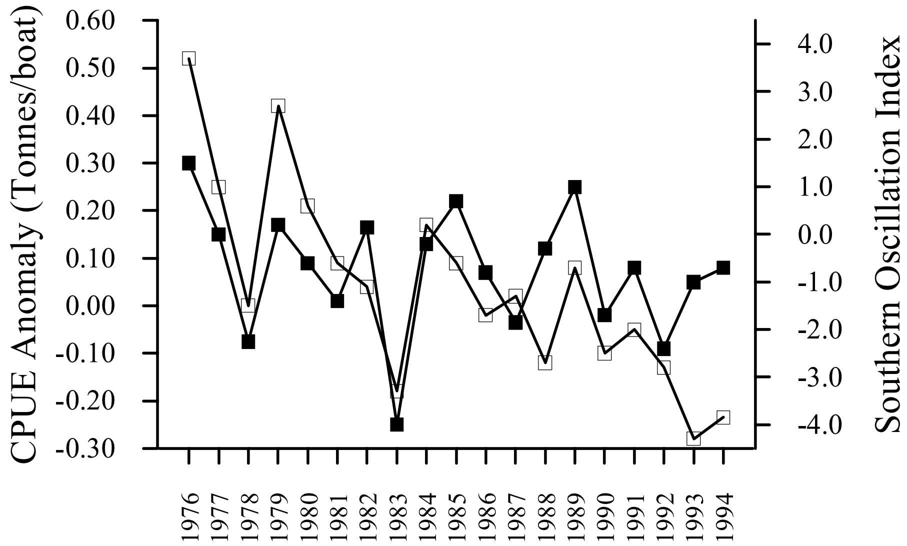
Fisheries for small-pelagic species are important throughout Africa's inland waters and support both substantial small-scale and 'industrial' level fisheries, particularly on the larger Rift Valley Lakes. The pelagic fisheries of Lake Tanganyika have received a great deal of attention from both fisheries development organisations and from the perspective of biodiversity conservation (reviewed in Molsa et al., 1999)

While there is little readily available information on how people adapt to climate-induced change around Lake Tanganyika, there are a number of recent studies that provide among the region's best (but still disputed) available evidence for links between global and regional-scale climate variability and change, and system and fishery productivity (O'Reilly et al., 2003; Verberg et al., 2003).

In Northern Lake Tanganyika, there is apparently a strong and significant relationship ($r = 0.62$, $p < 0.05$) between stock abundance anomalies of small pelagic clupeids, measured as the differences from the long-term average in Catch per unit of fishing effort by the Bujumbura-based industrial purse-seine fishery in Nov-Jan, and the Southern Oscillation Index or 'El Niño effect' in the previous Feb-March (Figure 5.11)

The downward trend in CPUE and lower SOI values (or more frequent anomalies) indicated in this dataset are complemented by observations of reduced wind-stress and increased surface water temperature in the recent publications by O'Reilly et al., (2003) and Verburg et al. (2003) and taken as evidence of long-term decline in productive potential of the lake due to global warming. Fishery declines and conflict around Lake Tanganyika have already driven many fisherfolk to other lakes, such as Lake Victoria and further decline in the fisheries – a major driver of regional trade and economic development in the lakeshore regions – can be expected to result in a wider economic decline in the region, given fishing's important 'multiplier' effects on the economies of remote and marginal regions of Africa (Allison, 2005).

Figure 5.11 Association between Southern Oscillation Index and catch rates of pelagic fish in Lake Tanganyika (Redrawn from Plisnier, 1997).



□ = differences from the long-term average in Catch per unit of fishing effort by the Bujumbura-based industrial purse-seine fishery in Nov-Jan
■ = Southern Oscillation Index or 'El Niño effect' in the previous Feb-March

5.4.3 River fisheries and climate change: Overview and a Bangladesh case study

Introduction

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 (Welcomme 1985; Junk *et al.* 1989). Fish have evolved physiological adaptations, life history strategies and spawning and feeding behaviour to cope with fluctuating flow conditions in rivers (Welcomme & Halls, 2004). Consequently, 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.

The impact of climate change on river fisheries and fisher livelihoods is likely to vary among river basins according to regional differences in the forecasted effects of climate change on the hydrological regimes of rivers and their floodplains. However, regional or river basin forecasts of regime changes are often lacking. Our ability to predict impact is further hampered by our largely incomplete knowledge and understanding of the way fish populations (and fishers) respond to changes to river hydrology.

Predicting the likely impact of climate change on river fisheries might therefore best be attempted by first examining how fish populations and species assemblages have, in the past, responded to natural inter-annual changes in river hydrology, as well as more lasting anthropogenic changes induced by the introduction of hydraulic engineering structures. These structures have the capacity to significantly modify many of the attributes or characteristics of river hydrological regimes including temporal flow patterns, overall velocity, floodplain inundation depth and duration, water temperature, turbidity, etc. By also drawing upon the results of simulation studies, potential impacts of climate change on fisheries and livelihoods may then be tentatively identified in relation to a range of potential hydrological regime change scenarios.

We adopt this approach below to determine potential impacts of climate change on fisheries and dependent livelihoods in Bangladesh – a country globally acknowledged as being extremely vulnerable to climate change (World Bank 2000) and for which climate and river hydrological regime change has been predicted. We begin by summarising the observed (and to some extent speculated) responses of fish populations to changes in important attributes of the hydrological regimes of rivers, and then describe corresponding predictions derived from a recently published simulation study.

Observed responses of river fish populations to hydrology and theoretical speculation[5]

<u>Flooding extent and duration</u>
Most unregulated large rivers seasonally inundate their adjacent floodplains providing important ephemeral feeding and nursery habitat and shelter from predators. The abundance and biomass of floodplain resident species and their predators are therefore believed to fluctuate in response to inter-annual variation in flooding extent (and duration) and corresponding critical habitat availability.

These inter-annual changes in exploitable biomass are reflected in reported landings. Many authors have found correlations between landings in year *y* and some flood index (FI) summarising the flood extent (depth or area) and/or duration (eg maximum water height, total meter days above bank-full height, etc) in the same year (*y*) or in preceding years (*y*-*n*) (See Table 5.8 below and Welcomme & Halls 2004).

Some authors have also found correlations between catches and the amount of water persisting in the system during the low water (dry season) period, notably University of Michigan *et al.* (1971) and Quiros and Cutch (1989). The dry season is a period of great stress to the majority of river fish species. At this time most species are confined to the main channels of the river although some specialists can survive in permanent floodplain waterbodies. Model predictions described by Halls *et al.* (2001) suggest that the biomass of floodplain-resident *blackfish* species (*sensu* Regier *et al.* 1989), is more sensitive to dry than

[5] This section draws heavily from Welcomme & Halls (2004) and Halls (1998).

flood season conditions when the area of water remaining on the floodplain may be less than 5% of that during the flood season.

It remains largely uncertain whether the reported correlations between catch and FI described above reflect diminished competition among populations as available food and shelter per individual increases with flooded area and volume (density-dependent effects) or whether changes in primary production per unit flooded area or volume are also important (density-independent effects). Of course these correlations could also reflect changes in fishing effort and gear efficiency, but both effort and gear efficiency would be expected to decrease, not increase with more extensive flooding as fish densities are lowered and fishing operations become disrupted.

However, what is apparent from these empirical relationships is that if competition (density-dependent) effects are not important (*i.e.* if food and shelter are not limiting), then increased primary production would not lead to improved fish growth and catches. In other words, these empirical relationships must, at least partially, reflect the effects of density-dependent processes on the population. Density-independent effects are simply likely to exaggerate or diminish them depending on whether the effect of flooding on primary production per unit flooded area or volume is positive or negative, respectively.

Greater uncertainty surrounds the relative importance of density-dependent effects on the three main population regulation processes (growth, mortality and recruitment). Le Cren (1958), Kapetsky (1974), Backiel & Le Cren (1978) and Welcomme (1985) all report evidence of density-dependent growth although Bayley (1988) found evidence of this process only among certain types of Amazonian species possibly reflecting the special conditions of the Amazon where fish densities never reach levels where the process becomes important. However, the modelling predictions described below appear largely robust to where these processes are assumed to be operating (see later).

Flood Timing

The timing of the flood is important to many river fish species which have defined breeding seasons centred upon a particular flood phase (see Lucas & Baras 2001 for a detailed review of migration). Migratory, *whitefish* species (*sensu* Regier *et al.* 1989), such as *Prochilodus* (Bonetto & Pignalberi, 1964; Bonetto *et al.*, 1971) or the cyprinids of the Mekong, are especially sensitive to the timing of the flood because they begin their migration from downstream feeding habitat during the dry season, timing their migrations so as to arrive at the upstream spawning site before, or contemporaneously with, the rising flood (Fuentes & Espinach Ros, 1998). Such species may mature during migration or at upstream sites, postponing the last stages of maturation until the waters begin to rise (Welcomme & Halls 2004).

Total spawners (*sensu* Lowe-McConnell 1975), such as many characin, cyprinid and siluroid species, tend to have semi-pelagic eggs and larvae that enter the drift. Predatory species have been observed to migrate further upstream than the prey species so that, after drifting downstream, their larvae achieve a size at which they are able to feed upon the prey species. Little is known of the flexibility of such behaviour and its tolerance to substantial temporal displacement of the rising flood phase (*ibid*).

Timing is also important over shorter periods. In the Mekong, and possibly other systems, migration and reproduction are closely linked to the lunar cycle (Sao Leang & Dom Saveun 1955). Significant departures from existing hydrological conditions during this cycle may not favour breeding in such species, especially in the flashier regimes of upstream reaches. Many small cyprinid and characin species that have a defined breeding season during the rising flood, timing the release of eggs to enable their fry to be washed onto the floodplain by the advancing waters are also likely to be impacted by changes in flood timing (*ibid*).

Timing of floods is also important for climatic reasons. In many temperate and sub-tropical regions the flood coincides with rising temperatures of spring and summer. This favours the growth of young fish by increasing the amount of food available and the rate at which it can be metabolised. Delays to flooding until late summer or early autumn in most rivers might result either in failure of fish to spawn, or diminished growth and survival of juvenile fish due to lower floodplain productivity in the cooler season.

Smoothness and Rate of Change

The smoothness of the flood is a measure of the steadiness of the rise and fall of the waters. Fish faunas of smaller rivers and low order streams must have reproductive and shelter-seeking behaviour that are adapted to sudden changes in the discharge if they are to survive. However, species living in higher order systems are usually better adapted to smoother flood curves. The smoothness of the flood curve is particularly critical for total spawning white fish, as temporary recessions can interfere with larval drift in the same way as discontinuities in flooding. However, severe fluctuations in level also pose potential difficulties for marginal spawners and some classes of nest builders such as *T. zillii*, which can repeatedly move its eggs to new nest sites as water levels rise. Excessive, rapid variation in level can submerge nests of bottom breeding species to unviable depths. Tilapias, *Oreochromis, Sarotherodon* and Tilapia species, for example, will tolerate only a narrow range of depths and substrate types for their nests. If the water is too deep, turbidity and low light levels do not permit them to complete their breeding. Equally retreating waters could expose nests leaving the eggs and fry to desiccate. Rapid changes in level can also strand attached egg masses of the marginal spawning phytophils resulting in the failure of that batch of spawn (*ibid*).

The rapid currents associated with such transitions in water level can sweep larvae and eggs of phytophilous species past their appropriate destination. During the falling water (draw down) period, an overly rapid retreat of water is commonly assumed to increase the risk of fish becoming stranded in residual pools and channels elevating mortality rates. Similar arguments apply to many of the invertebrates that serve as one of the major food sources for the growing fish (*ibid*).

Discharge Rates

Populations of white fish species that migrate upstream to breed in the channel and whose fry drift downstream to be eventually washed onto floodplain nursery habitat, are likely to be most affected by changes in river discharge rates. Whilst the influence of different flood regimes on the survival and growth of drifting fry is poorly understood, it does seem likely that accelerated flows would result in the drifting fry being swept past suitable floodplain nurseries.

Diminished flows may not inundate floodplains (flood failure) resulting in the loss of whole year classes of fish (Gaygalas and Blatneve, 1971; Fuentes 1998). Extremely low flows can also lead to deoxygenation of the water leading in extreme cases to elevated mortality rates, particularly among whitefish species.

Summary

Observed responses of river fish populations to changes in hydrology are summarized in Table 5.8 (overleaf).

Table 5.8 Summary of the impacts of changes to river hydrology river fish populations and assemblages (modified from Halls 1998).

	Effect on fish and fisheries	River/Location	References
Temporal changes in river flow	(a) Disruption of spawning patterns through inappropriate stimuli or unnatural/unpredictable short-term flows leading to changes in community structure favouring species with more flexible spawning behaviour.	(a) Volga River, Russia; Niger River, Nigeria; Columbia River, USA; Cauvery River, India; Hanjiang River, China; Waikato River, New Zealand; Lake Itezhi-tezhi, Zambia; Red River Oklahoma, USA; Mahaweli Ganga, Sri Lanka; Hawkesbury River, Australia	(a) Chikova (1974); Eliseev & Chikova (1974); Lelek & El Zarka (1973); Adeniji (1975); Otobo (1978); Sagua (1978); Trefethen (1972); Sreenivasan (1977); Liu & Yu (1992); Swales (1990); Kapasa & Cowx (1991); Winston *et al* (1991); Smith & Jiffry (1986); Harris (1988)
	(b) Failure and unpredictable flood patterns strand fish and spawn in floodplain pools.	(b) Volga River, Russia; Hill streams, Himalayas, India; Nidelva River, Norway;	(b) Eliseev & Chikova (1974); Joshi (1987); Hvidsten (1985);
Shift from pulse regulated to stable system dynamics	(a) Reduction in productivity at community level.	(a) N/S.	(a) Welcomme (1985)
	(b) Changes in species composition favouring pelagic planktivors, sight feeding carnivores and tributary species.	(b) Lower Missouri River, USA.	(b) Pflieger & Grace (1987)
Decrease in river velocity	(a) Shifts from reophilic to lentic communities	(a) Colorado River, USA; British Columbian rivers, Canada.	(a) Holden & Stalnaker (1975); Holden (1979); Poddubnyi (1979); Tolmazin (1979); Marshall (1982); Hirst (1991)
	(b) Reduced flushing rates resulting in accumulation or low dilution of toxic wastes or anoxic conditions leading to fish mortalities.	(b) Volga River, Dnieper, Dniester, Russia; Danube, Europe; Finnish reservoirs, Finland; Savannah River, USA; La Grande hydroelectric complex, Quebec, Canada; Churchill River, Canada; Sulby River, Isle of Man, UK; Don River, Russia.	(b) Welcomme (1985);Tolmazin (1979); Verta *et al* (1985); Abernathy, (1985); Verdon *et al* (1991); Strange *et al* (1991); White *et al* (1990); Kovtun & Nikul'-shin (1989).
	(c) Fish community dominated by limnophilic species	(c) River Rhone, Europe	(c) Fruget (1992)
	(d) Sedimentation of spawning grounds.	(d) Trinity River, USA; Himalayan hill streams, India, North Tyne streams, UK	(d) Nelson *et al* (1987); Joshi (1987); Sear (1993);

Increase in river velocity	(a) Fish larvae, fry and juveniles swept past appropriate sites for colonization. (b) Spawning beds destroyed by down cutting (erosion) of river bed.	(a) Danube, Russia (b)Vistula River, Poland	(a) Zambriborsch & Nguen Tan Chin (1973); Bacalbasa-Dobrovici (1985); (b) Backiel & Penczak (1989)
Changes in mean temperature caused by low flow regimes.	(a) Impact on spawning success of different species/ delayed spawning	(a) Colorado River,Cowgreen Reservoir, UK; Hanjiang River, China	(a) Holden & Stalnaker (1975); Holden (1979); Crisp & Mann (1991); Liu and Yu (1992)
Reduced floodplain inundation; loss of floodplain area and reduction in habitat diversity.	(a) Reduction in overall fish production resulting from loss of suitable spawning and feeding habitats. (b) Change in species composition with loss of obligate floodplain spawners.	(a) Missouri River, USA; Mogi Gassu-Rio/ Grande system, Brazil; Volga River, Russia; Niger River, Nigeria; Illinois River, USA; Murray-Darling river system, Australia; River Danube, Europe; Warta River, Poland; Pongolo River, South Africa (b) Indus River, Pakistan/India; Middle Danube, Yugoslavia; Murray River, Australia; Mississippi, USA; Nyamunas River, Russia	(a) Whitley (1974); Godoy (1975); Koblitskaya (1984); Awachie (1978;1979); Welcomme (1985); Starret (1972); Sparks & Starrett (1975); Gehrke (1992); Bacalbasa-Dobrovici *et al* (1990); Penczak (1992); Gehrke (1992); Merron *et al* (1993) (b) Welcomme (1985); Butcher (1967); Bryan & Sabins (1979); Gaygalas & Blatneve (1971); Fuentes 1998.
Changes in flooding patterns on the floodplain	(a) General reduction in productivity of whole system resulting from shortened flood season. (b) Poor recruitment due to disrupted nutrient exchange	(a) Various Rivers; Modified floodplains, Bangladesh (b) Nyamunas River, Russia; Murray-Darling river system, Australia	(a) Welcomme (1985) (b) Gaygalas & Blatneve (1971); Gehrke (1992)
Inter-annual variation in flooding extent and duration.	(a) Correlations between landings and various flood indices.	Serbian and Slovakian Danube; Amur River, Cross River; Orinoco River; La Plata system; Pilcomayo River; Amazon River; Niger River; Mahakam River; Mekong River.	Stankovic & Jankovic (1971); Krykhtin (1975); Holcik & Kmet (1986); Holcik (1996); Moses (1987); Novoa (1989); Quiros & Cutch (1989); Payne & Harvey (1989); Lambert de Brito Ribeiro & Petrere (1990); Welcomme (1979); Lae (1992); Christensen (1993); Baran et al. (2001). University of Michigan et al. (1971); Quiros and Cutch (1989). Also see reviews in Welcomme (2001) and Welcomme & Halls (2004).
Large fluctuations in water levels	(a) Spawning/reproduction ceases	(a) Barke Lake, USA	(a) Wilton (1985)

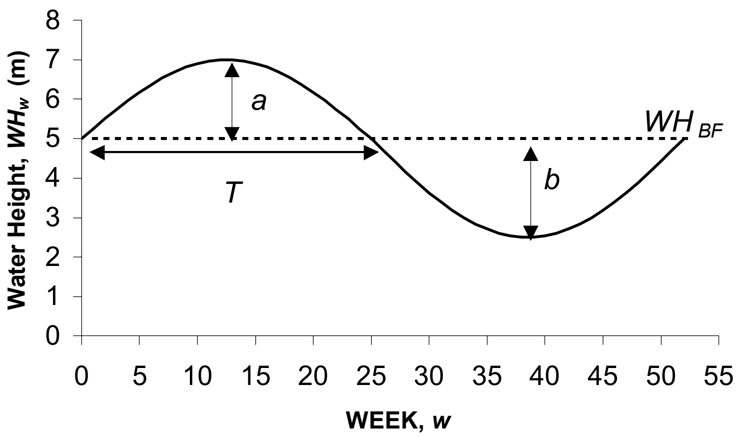
Reduction in habitat diversity.	(a) Reduction in species diversity, stability and biomass. (b) Reduction in mean size of fish.	(a) Missouri, USA; rivers and streams in the USA; Kissimmee River, USA; River Rhone, Europe; Californian wetlands, USA; Prairie streams, Iowa, USA; middle Danube, Czechoslovakia; Twitty's Creek, USA; Twentymile Creek, Mississippi, USA; western Washington streams, USA; Yalobusha River, Mississipi, USA (b) Middle Danube, Czechoslovakia; Blackwater River, Missouri, USA	(a) Welcomme (1985); Congdon (1973); Adkins and Bowman (1976);Gorman & Karr (1978); Groen & Schulmbach (1978); Burke & Robinson (1979); Tarplee *et al* (1971); Jahn & Trefethen (1973); Sedell, Yuska and Speaker (1983); Toth (1993); Fruget (1992); Faber *et al* (1989); Scarnecchia (1988); Holcik (1990); Keffer & Maughan (1985); Loftin, (1991); Sheilds & Hoover (1991); Knudsen & Dilley (1987); Jackson (1993) (b) Jahn & Trefethen (1973); Holcik (1990)
Increase in silt loading	(a) Reduction of habitat and community diversity: loss of species: (b) Increase in deposition causing choking of substrates thereby effecting reproductive success of lithophils/psammophils. (c) Migrations restricted or prevented. (d) Changes in density of vegetation usually favouring phytophils. (e) Changes to benthos leading to restructuring of fish community toward illiophages.	(a) N/S (b) N/S (c) N/S (d) Missouri, USA; middle Danube, Czechoslovakia (e) Missouri, USA	(a) Welcomme (1985) (b) Welcomme (1985) (c) Welcomme (1985) (d) Welcomme (1985); Holcik (1990) (e) Welcomme (1985)
Decrease in silt loading	(a) Decrease in deposition causing reduction in non-visual predators and omnivores within the fish community in preference to pelagic planktivores and visual predators.	(a) Missouri River	(a) Welcomme (1985); Pflieger & Grace (1985)
Drowning of spawning substrates	(a) Decline in lithophils and psammophils.	(a) Middle Danube, Czechoslovakia	(a) Welcomme (1985); Holcik (1990)

Potential Impacts Forecasted On The Basis Of Simulation Studies

The population dynamics of fish in large floodplain rivers are believed to respond to hydrological conditions in a density-dependent manner (Welcomme & Hagborg, 1977). Using an age-structured population dynamics model incorporating sub-models describing density-dependent growth, mortality and recruitment, Halls & Welcomme (in press) explored how hydrological conditions within a theoretical floodplain river system may affect the dynamics and exploitable biomass of *Puntius sophore* - a common cyprinid that contributes to between 30-50% of the total landed weight of freshwater fish species in many parts of Bangladesh. *Puntius sophore* shares very similar characteristics to those of *Henicorhynchus* species that dominate catches in the Tonle Sap and Lower Mekong rivers, as indeed with many fishes in heavily exploited rivers that rely mainly on individuals belonging to the 0+ and 1+ cohort to supply the fishery. These common characteristics include rapid growth, small maximum size and sexual maturation by the end of their first year.

Populations were exposed to a range of different hydrological conditions in the hypothetical river system by varying the duration of flooding, *T*, the maximum flood height, *a* and the minimum dry season water level, *b* (Figure 5.12). By varying these three parameters, the total volume of water passing through the system in any year was varied by more than a factor of 5.

Figure 5.12 The parameters of the water height (WH) model used to generate a range of different hydrological conditions within the hypothetical river system. BF-Bankfull height. Source: Halls & Welcomme (in press).



To generate this range of volumes, *a* was varied from 0.5m to a maximum of 3 m, *b* was varied between -0.5m and -4.5m whilst *T* was varied from 10 to 25 weeks (typical of the flood duration range of most unmodified river systems). Combinations of parameter values were constrained only to those that generated flood season volumes that exceed those of the dry season to allow for the effects of evapo-transpiration, abstraction and other losses between the two periods.

The sensitivity of the model predictions to the assumptions concerning density-dependence was examined by repeating the simulations with each possible combination of density-dependent effects in the model (Table 5.9).

Table 5.9 Combinations of density-dependent effects included in the model simulations.

Model Assumption	Growth	Mortality	Recruitment
1	DD	DD	DD
2	DD	DD	CONST
3	DD	CONST	CONST
4	DI	DD	CONST
5	DI	DD	DD

DD - density-dependent, DI - Density-independent; CONST –Constant.

The results of the simulations indicated that the relationships between exploitable biomass and the three combinations of hydrological variables considered all exhibited very similar patterns across the range of flood season durations examined, although exploitable biomass tended to increase with flood season duration, *T*. Except under model assumption 5, this pattern was also found to be very consistent under all four remaining model assumptions. Biomass is predicted to increase to a maximum as the flood and dry season variables examined increase simultaneously (Figure 5.12). In other words, exploitable biomass is maximised when both flood and dry season depths or areas or volumes (and flood season duration) are simultaneously maximised.

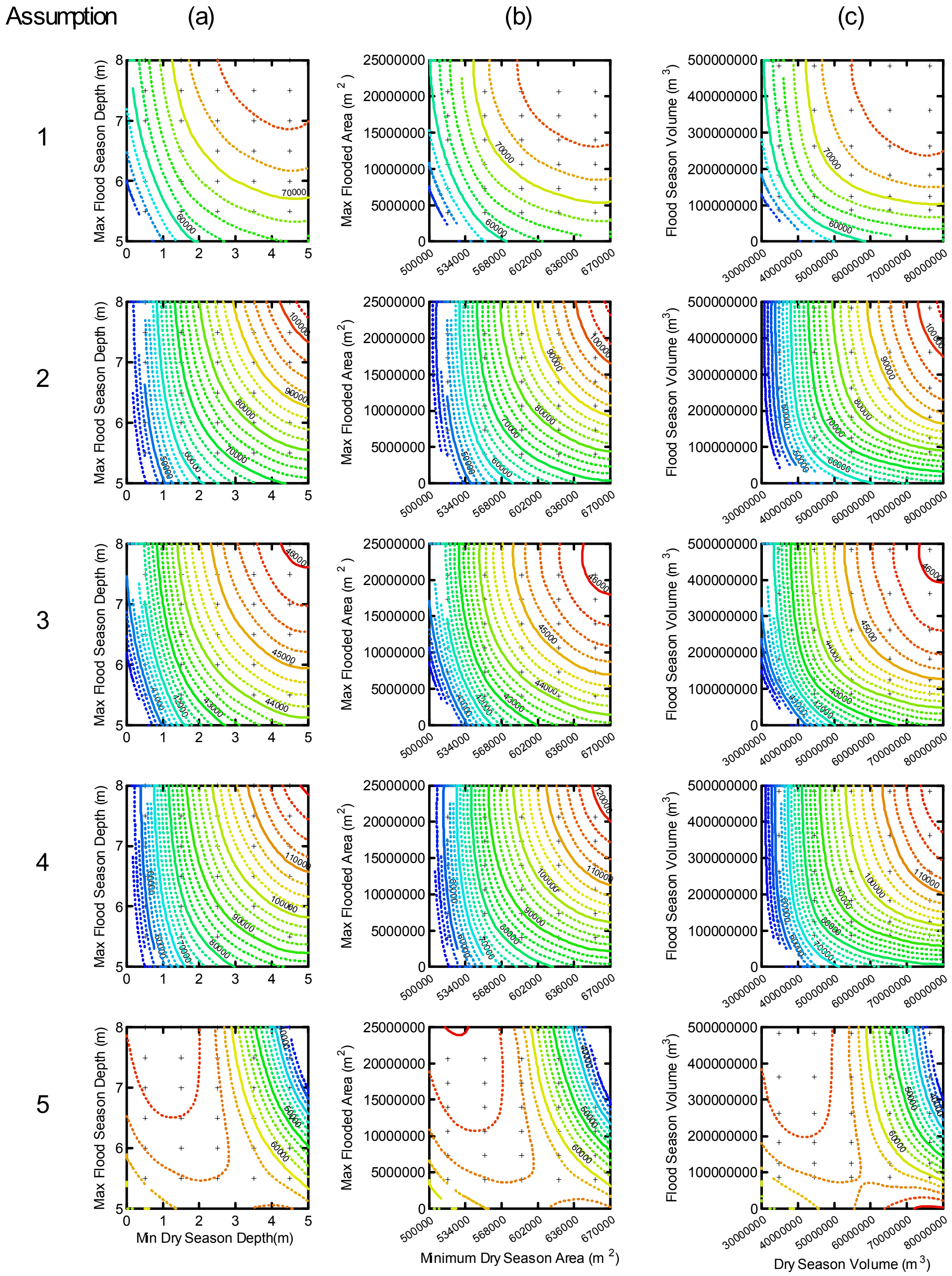
These predictions imply that when flood seasons, depths, areas and volumes approach their maximum, exploitable biomass is determined almost exclusively by their dry season equivalents and *vice versa*. In other words, losses in biomass arising from reductions in depth, area or volume during the flood season may be compensated by increases to their magnitudes during the dry season.

Under model assumption 5, a more complex picture emerges where maximum exploitable biomass corresponds to the maximum values for depth, flood area and volume during the flood season flood, but followed by a relatively short period of low dry season depths, areas and volumes (Figure 5.13, overleaf). This reflects the effects of the compensatory nature of the stock recruitment relationship used in the model (see below). Exploitable biomass is also predicted to increase with increasing flood season duration (not illustrated).

Summary

The general message that emerges from these simulations is that exploitable biomass is predicted to be maximised by simultaneously maximising flood and dry season depths, areas or volumes and flood season duration to create a long, competition-free growing season and a short, but deeply flooded dry season that minimises the effects of density-dependent mortality. In effect, this suggests that exploitable biomass is predicted to increase with increasing hydrological stability more typical of lakes or reservoirs (Halls & Welcomme in press). Conversely, diminished and less stable flooding conditions would be expected to reduce exploitable biomass.

Figure 5.13 Predicted response of exploitable biomass to minimum dry season and maximum flood season (a) depths and (b) areas, and (c) total flood and dry season volumes, under the five different model assumptions



For the sake of brevity, only the results only for a flood duration, *T* =25 weeks are shown. Source: Halls & Welcomme (in press)

Experience from dam projects around the world does, however, suggest that a shift from flood *pulse-regulated* to more *stable system* dynamics upstream of dams can bring about changes in community structure and overall production (see Table 1). The most widely reported causes for these changes upstream (not including the interruption of migratory pathways by dam walls or levees) are the disruption of flow or thermal-based spawning cues, and reduced primary production and critical habitat availability as "dynamic edge effects" (Junk *et al* 1989) become diminished. Observed differences in yield among rivers and natural lakes may reflect the importance of these dynamic edge effects. Bayley (1991) quotes yields of up to 125 kg ha^{-1} yr^{-1} in rivers compared to 97kg ha^{-1} yr^{-1} in lakes in Africa (*ibid*).

The model predictions described above appear largely robust to the density-dependent assumptions underlying the model. Similar response patterns emerge regardless of where the density-dependent processes are assumed to be operating in the model. The major exception to this is when growth is modelled to be density-independent and both recruitment and mortality are both modelled to be density-dependent (model assumption 5). The complex patterns that emerge from this combination reflect the compensatory Ricker stock-recruitment relationship used in the population model. This relationship predicts that at low spawning stock densities, recruitment increases with spawning stock density (corresponding to the left hand limb of the curve) up to a certain point, and then declines with further increases in stock size (the right hand limb of the curve). Recruitment in most exploited fish populations typically corresponds to the almost linear left hand limb of the stock-recruitment curve, so these complex compensatory recruitment effects would generally not be expected. Density-dependent growth produces a similar effect by effectively moving the population to this left hand limb by reducing individual fecundity (*ibid*).

Potential Impact on Climate Change on the Vulnerability of Fisherfolk in Bangladesh – A Case Study

<u>Introduction</u>

Bangladesh lies in the delta of three large rivers, the Ganges, Brahamaputra and Meghna (GBM) where most elevations are less than 10m above sea level. A complex network of 230 rivers, (57 of which cross internal boundaries) drains 175 million hectares, of which 92% lies outside the country in India, Nepal, China and Bhutan. The low lying topography coupled with a funnel-shaped coast exposes the country to cyclones, tidal surges and seasonal floods. On average, approximately 20% of the area of the country or 3 million ha is inundated each year during the monsoon season (June-September). Both the fisheries and agricultural sectors of the economy rely heavily upon the seasonal rainfall and floodplain inundation for their production. Extreme flood events may inundate up to 70% of the country. Catastrophic flooding in 1998 left millions homeless and caused U.S. $3.4 worth of loss and damage (Mirza *et al.* 2003).

The population of 138 million is growing at 1.7% per annum making it the most densely populated country (935 inh km^{-2}) of significant area. Despite sustained domestic and international efforts, Bangladesh remains one of the world's poorest and least developed nations. Fifty-percent of the population is below the national poverty line, the same proportion of children suffer malnutrition, and 40% of the population is illiterate (World Bank 2004).

Some 90 million people depend upon the country's floodplains for their livelihoods, the majority exploiting the natural resource base, while more than 50% are classified as functionally landless[6]. Resource use patterns are adapted to the temporally and spatially dynamic interface between terrestrial and aquatic natural resources. These and other factors described by World Bank (2000) combine to make the country extremely vulnerable to natural hazards and climate change. Households build portfolios of livelihood strategies to reduce vulnerability. Marginal rural families, for example, increasingly depend upon a mixed portfolio of share-cropping, agricultural and non-agricultural wage labouring, fishing, migration to work elsewhere, and remittances from relatives abroad. Meanwhile, for the whole population, land sub-division due to inheritance laws and crisis sales results in increasing landlessness and increasing pressure on common-pool resources, particularly fisheries because of the low entry costs involved (Dixon *et al.* 2003).

Fisheries and Livelihood Dependence

Whilst the fisheries sector contributes a modest 3.3% to GDP compared to more than 10% from agriculture, the population relies upon the country's fisheries resources for approximately 80% of the daily animal protein intake (Craig *et al.* 2004). Fish products (mainly shrimp) also generate important export earning. Besides the harvest sector, the fisheries of Bangladesh provide employment for approximately 2 million people including gear makers, fish traders, transporters, packers and other related occupations (Dixon *et al.* 2003).

It is estimated that 67-75 % of all households fish at some time of the year either for subsistence, to supplement incomes, or as their main occupation. Typically, three categories of fisheries are recognised: subsistence, seasonal (part-time) and professional (largely full-time). Subsistence fishers are opportunistic. Seasonal fishers are primarily landless and marginal farmers - a group which has expanded recently is response to the aforementioned inheritance laws and crises sales. Fishing is the primary occupation of professional fishers. De Graaf and Martin (2000) found 68% of households' fish for subsistence, catching about 30% of the total annual catch, while only 1% of households were full-time fishers. Seasonal fishing activities largely take place when return to effort is highest and/or when other livelihood activities (particularly in agriculture) are limited.

Subsistence fishers tend to employ cheap and simple gears such as push nets or hook and line and may not devote much time to fishing. Those who fish on a more intensive, if not seasonal basis, generally invest in gear which gives a better return to effort, is still affordable, and may be operated by one individual. Full-time fishers are most likely to invest in gear which gives high return to effort, but which is more expensive (eg seine nets) and may require team effort to purchase and/or operate. By contrast large barrier type or fish aggregating gear are expensive and are likely to be owned by wealthy non-fisher individuals (Dixon *et al*. 2003).

The seasonality of fishing corresponds to changes in fish density in response during the rising and falling water (draw-down) periods. Traditional fishers often make seasonal migrations to take advantage of differences in the timing of the rise and draw down periods in different regions of the country.

[6] Owning less than 0.2 ha of land for cultivation.

The majority of full-time fishers live below the poverty line, most are landless and many do not have homestead land, but build their houses on river banks subject to flooding. Lacking collateral, few have access to bank credit, instead relying upon private money lenders who usually charge a very high rate of interest. Fishers' educational and health status tends to be low. Income from fishing is generally much lower during the dry compared to the flood season reflecting changes in fish densities and subsequent catch rates. Without savings or access to credit, many professional fishers become particularly vulnerable to shocks and trends during the dry season period often being forced to migrate long distances in search of labour.

Part-time (seasonal) fishers typically fish during the flood season when access to the fishery is open to all. The poorest members of this group supplement their fishing income with agricultural work and other non-fishing activities during the dry season. Their numbers have increased in response to pressure for land and because fishing complements the timing of agricultural activities which requires most labour during the dry season. This group may be landless and marginal farmers, or in the case of more profitable fisheries, small and medium landowners who intensively exploit the seasonal floodplain fishery. For this group, fishing is an important component of their livelihoods. Between 20-70% of seasonal fishers are either poor or very poor, and landless, although many have homestead land. Fishing gear ownership is limited and of a simple variety. They often work as fishing wage labourers while depending upon agricultural labouring as an additional source of income. Most are illiterate and have poor health status. Degradation of fisheries resources would significantly limit this group's opportunity for local seasonal livelihood diversification. In order to make up short-fall in household needs, male members would either have to seek employment in petty trade or off-farm employment, or join the large number of seasonally migrant agricultural labourers, potentially increasing the vulnerability of remaining household members to shocks and trends.

Subsistence fishers are opportunistic responding to seasonal changes in access rights and fish abundance to catch fish mainly for their own consumption using inexpensive, simple gear types. This group includes the landless, small farm owners, women and children. Members of this group do not regard themselves as fishers, although they may sell a proportion of their catch. Up to 50% of the members of this category are considered poor or very poor, most are landless and few own homestead land. Their livelihoods are based around agricultural labouring, transport, and share cropping. Climate change impacts on fisheries would threaten the food security of this group.

Dixon *et al.* (2003) report that the numbers of fishers (both full and part-time), and the number of gears operated per individual are increasing in Bangladesh along with other countries south and south-east Asia.

<u>Predicted Changes in Climate</u>
During the next 50 years, temperatures in Bangladesh are predicted to increase by 1.1^{o} C during the flood season and by 1.8 ^{o} C during the dry season. Models for precipitation predict overall increases in annual precipitation, with a possibility of increasing monsoon precipitation (May to September), and decreasing dry season precipitation (December to February). Sea level is predicted to increase by 50cm (World Bank 2000).

Predicted Changes to Hydrological Regimes in Rivers and their Floodplains

Climate change is anticipated to effect cross-boundry river flows, as changes in global temperatures would affect the timing and rate of snow melt in the upper Himalayan reaches. As a result the hydrological regimes of GBM river system could alter significantly (World Bank 2000). Drainage congestion is forecasted to be a major problem. The combined effect of higher seas levels and river beds, and reduced sedimentation in flood protected areas will impede drainage, increasing the depth, duration and extent of floodplain inundation.

Depending upon the choice of Global Circulation Model (GCM) model employed, Mirza *et al.* (2003) predicts that mean annual discharge rates in the Ganges and Megna Rivers could increase by as much as 60% assuming a 6^{o}C rise in global mean temperature. Increases in mean discharge rates in the Brahamaputra river are predicted to be in the order of 20%. Consequently rates of sedimentation are also expected to increase (World Bank 2000).

Mirza *et al.* (2003) also predict that in response to these changes in discharge rates, mean flooded area will increase from 3.77 to between 4.65 and 5.24 million ha depending upon rises in global mean temperature, equivalent to increases of between approximately 20-40%. Under a 6^{o}C rise in global mean temperature scenario, the duration of floodplain inundation is also predicted to increase.

Low flows and increased evapotranspiration during the dry season caused by reduced precipitation and elevated temperature will put increasing pressure on water availability during this period. Climate induced moisture stress in the upstream river basin area might lead to even lesser availability of water during this period (World Bank 2000).

Saline water intrusion is also predicted to increase further upstream as a result of a number of factors including higher seas levels and diminished river discharge rates during the dry season.

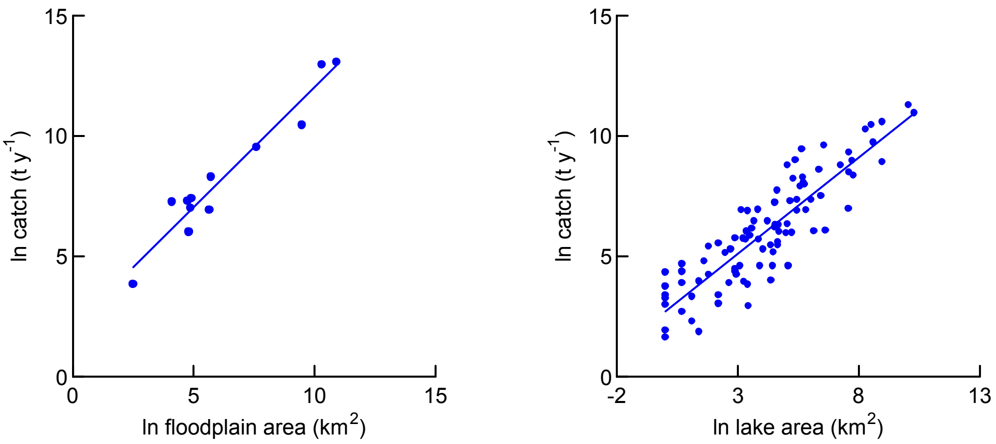
Increased frequency and intensity of extreme events including flooding, droughts cyclones, and storm surges is also forecast. A one-in-twenty-year extreme flooding event is likely to become a one-in-five-year event (Huq 1998).

Predicted Impacts on Fisheries and Dependent Livelihoods

Increased flooding extent and duration

Temporal and among fishery observations (see Figure 5.14 overleaf and text above) would suggest that total annual landings in Bangladesh are likely to increase in response to increased mean flooded area. The results of simulation studies described above are consistent with these predictions and also predict that fish yield will increase in response to prolonged flooding.

Figure 5.14 Potential yield from (a) Asian floodplain rivers; and (b) African lakes and reservoirs plotted as functions of resource area with fitted regression lines on $\log_e$ transformed scales. For (a) $\log_e$ catch = 2.086 + 0.996 $\log_e$ area (R=0.97; P<0.001); and (b) $\log_e$ catch = 2.668 + 0.818 $\log_e$ area (R=0.90; P<0.001). Source Halls *et al.* (in press).



The magnitude of this increase is, however, difficult to predict with any certainty given the assumptions underlying the empirical and simulation models. On the basis of the predicted increase in flooded area of between 20-40% by Mirza *et al.* (2003), the empirical model illustrated in Figure 3a, predicts a corresponding increase in total annual yield of between approximately 60,000 and 130,000 t.

However, these potential gains must be viewed against potential losses arising from increased mean discharge rates, reductions in dry season water volumes and flooded area, increased saline water intrusion and more frequent extreme flood events.

Increased peak and mean river discharge rates may diminish populations of white fish species that migrate upstream to breed in the channel and whose fry drift downstream to be eventually washed onto floodplain nursery habitat. Elevated discharge rates are likely to reduce recruitment in these species as fish larvae, fry and juveniles are swept past suitable floodplain nursery habitat. Increased down-cutting (erosion) of the river bed may also diminish recruitment in populations of fish that spawn on the beds of rivers. Significant temporal changes in river discharge rates may also disruption spawning in some species leading to changes in community structure favouring species with more flexible spawning behaviour. More catastrophic and unpredictable climatic events may also disrupt fishing operations, effectively reducing fishing effort and potential yield.

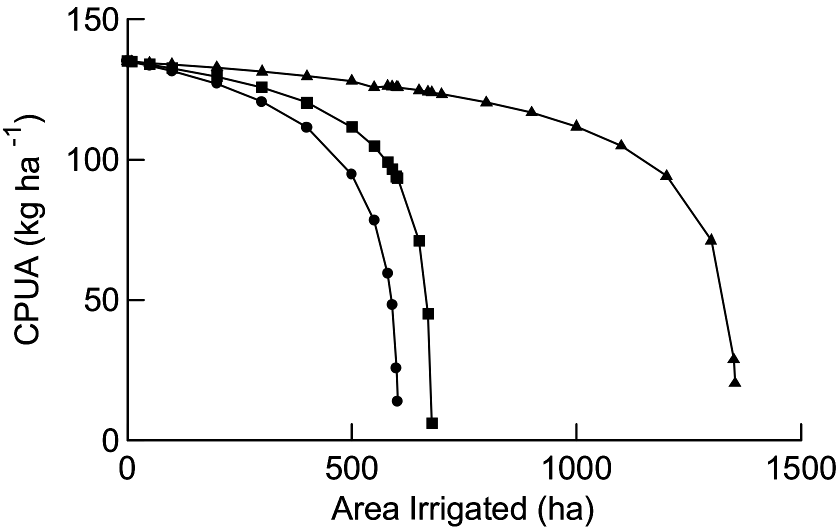
Adaptive strategies focusing upon the construction of more flood control embankments aimed at mitigating forecasted climate change impacts on the agricultural sector are likely to further exacerbate the negative impacts on fisheries. Studies described by Halls *et al.* (1998;1999) suggest that fish production can be 50% lower inside flood control schemes compared to outside due largely to diminished recruitment of high value migratory whitefish species and the passive drift of larvae from rivers to modified floodplains. The construction of more embankments will further constrain flow to the main channel, increasing peak and mean discharge rates and the likelihood of catastrophic flooding events.

Predicted increased rates of sedimentation may choke spawning substrates, affecting the reproductive success of lithophils and psammophils, bring about changes to the benthos favouring illiophages, and block migration routes of whitefish and greyfish, combining to reduce fish diversity and exploitable biomass.

On the basis of the results of the simulation studies described above, the predicted reductions in precipitation during the dry season and corresponding reductions in dry season water volumes and flooded areas are also likely to further reduce exploitable biomass. This impact may be amplified by an increasing reliance upon high-yielding crop varieties grown within flood control schemes, some of which must be irrigated during the dry season months. Irrigation systems often extract surface water from residual bodies remaining during the dry season after flood waters have receded. These residual water bodies provide critical dry season habitat for blackfish and greyfish species. Shanker *et al* (2004) have shown that, beyond some threshold, floodplain fish production is highly sensitive to removals of water from these bodies (Figure 5.15 overleaf) impacting upon fish catchability, natural mortality rates and recruitment. Increased rates of siltation may further reduce the depth and surface area of dry season water bodies, transforming many from a perennial to a seasonal type. ISPAN (1992) report a 70% reduction in the water area of an important floodplain lake in North Central Bangladesh over a 15 year period as a result of siltation processes.

Higher forecasted temperatures will also decrease the solubility of oxygen in residual dry season waterbodies, potentially elevating rates of natural mortality. This problem will become more serious as the size of remaining water bodies diminishes in response to increased evapotranspiration rates and dry season irrigation. Increased saline water intrusion may also reduce available habitat for most species of fish leading to further reductions in exploitable biomass.

Figure 5.15 Predicted response of annual catch per unit area (CPUA) to changes in the area of land irrigated for dry season Boro rice cultivation for low (▲); intermediate (■); and high (●) irrigation schedules in part of the Pabna flood control and irrigation compartment, North-West Bangladesh.



Source: Shankar et al. (2004)

Implications for Livelihoods
The net effect of these positive and negative impacts on floodplain-river hydrology in Bangladesh is extremely difficult to forecast. Any net increases in overall fisheries yield and associated livelihood benefits such as improved earnings and food security are likely to come at the expense of reductions to species diversity and greater fluctuations in total annual landings potentially increasing livelihood vulnerability.

Longer, deeper floods might benefit the landless and seasonal fishers, as access to the fishery will remain open for longer, but drainage congestion and standing water may increase the risk of outbreak of cholera and other waterborne and diarrheal diseases such as malaria, dengue and dysentery (World Bank 2000).

Changes in the exploitable biomass of high value species in response to the construction of further flood control embankments may have the greatest impact on the poorest full-time fishers who primarily fish for income. Part-time and subsistence fishers may be less affected since they often do not have access to these resources or appropriate gear to exploit them.

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. Fishers are mostly poor or very poor and often without access to credit to cope with shocks and adverse trends. Typically they are poorly educated and less technically competent to understand changes in practices or new technologies to cope with the predicted changes. Their characteristic poor health and inadequate health care systems make them further vulnerable to extreme events and outbreaks of disease.

Mitigating impacts of changes to flood season hydrology by means of diversions and abstractions upstream will require international cooperation with countries sharing the GBM basin. Within country, institutional adaptations appear to have the greatest potential may help mitigate the impacts of climate change on dry season hydrology.

For example, crop diversification with an emphasis on more drought-resistant crops such as wheat and vegetables may help reduce fisherfolk vulnerability in areas where surface water abstraction for irrigation is widespread. Regulating surface and groundwater abstractions during the dry season may also be necessary.

Sluice gate management practices aimed at retaining more floodwater during the dry season may help compensate for the effects of changes in precipitation and dry season water volumes in flood control compartments. Such measures must however, ensure that 'dynamic edge effects' which are largely responsible for the fertility of the floodplain, are not diminished by creating less ephemeral conditions upon the floodplain (Halls *et al.* 2001).

Sluice gate management practices designed to take advantage of the strong migratory tendencies or fishes to enter flood control schemes and improving sluice gate design to maximize the passive drift of fry to modified floodplains might also be considered.

Physical adaptations such as dredging silted fish migration routes and critical dry season habitat may also help to reduce impact. Scope may also exist to excavate crude reservoirs on the floodplain providing both additional dry season refuges for fish and irrigation water.

5.5 Knowledge gaps and research agenda for climate change and fisheries

We have reviewed available information on future climate change scenarios, the mechanisms through which climate change may impact on fish stocks and fishery-dependent people and regions, and the extent to which people are able to adapt to past climate variability and change as an indicator of likely future adaptive capacity. We have examined these issues in a number of case-studies representing 'vulnerability hotspots', identified from a global analysis of risk exposure, sensitivity and adaptive capacity.

This analysis 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.

5.5.1 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. While we believe the analysis provides a valuable first step 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 and resulting physical habitat change could be related to ecological and livelihood responses and coping ability or resilience. Suggestions to improve methods and 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:

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

The most poorly resolved element of our global vulnerability analysis is that pertaining to exposure to future climate change. The current analysis utilises only projected temperature rise (country average of data based on IPCC scenarios) as a proxy variable for climate change, and assumes that more change signifies greater risk exposure and therefore a contribution to greater vulnerability. There is clearly a need to improve these assessments in future, by, for example:

- Exploring the effects of including projected changes in precipitation in vulnerability analyses - particularly for inland fisheries. Unlike temperatures, which are predicted to increase globally, precipitation levels may increase or decrease, depending on the region. Predicting the likely impacts of these changes will require understanding of the relationship between precipitation change and fisheries. In cases where precipitation is predicted to increase and fisheries are dependent on river flow, lake level or floodplain area, increased precipitation may be good for fish stocks, thereby potentially increasing the potential for inland fisheries as a source of nutrition and livelihoods. At the same time, increased flooding may expose other aspects of livelihoods or fishing operations to increased risks.

- 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).

2. Improving parameterisation of sensitivity and adaptive capacity

We have used national-level fishery statistics (landings, contribution to GDP, contribution to employment, contribution to nutrition) as indicators of the sensitivity of particular countries to the impacts of climate change. This analysis is largely constrained by the quality of available data (e.g. the data on number of fisherfolk is generally acknowledged by FAO to be poor, as it is based on census data that do not always identify fishing as a distinct occupation and cannot resolve the question of diversified livelihoods that include part-time fishing).

One area where the parameterisation could be improved is in 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.

A second research area related to data quality is the need to obtain data on poverty and HDIs specific to fisherfolk. At present, we have used national level data on poverty and HDI and assumed that the distribution of poverty among fisherfolk is the same as that for the general population. Little is known about the relative poverty status of fisherfolk, but what is known indicates that the relationship is complex, with some dimensions of poverty (e.g. net incomes) indicating relative wealth, while others (e.g. asset ownership, access to infrastructure and services, political representation) indicate extreme marginality (Béné et al, 2005). 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.

There is also a need to attempt to 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.

<u>3. Using 'expert elicitation techniques' to assess global and regional risks of climate change to fisheries and livelihoods</u>

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 (Morgan & Keith, 1995; van der Sluijs et al., 1998; Vaughan and Spouge, 2002). 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. Testing expert elicitation techniques in a fisheries context would be a useful means to unite research and policy in this field.

<u>4. Developing methods of vulnerability analysis for fisheries at different scales</u>

While it is recognised that vulnerability of fisheries and vulnerability of fishing-dependent communities are driven by external stressors and by underlying structural factors, the quantification and measurement of these driving forces have not been undertaken. Research in this area has already shown how development and well-being trends are linked to vulnerability and how exposure to climate change impacts can exacerbate vulnerability but the processes that link risk exposure to vulnerability are not well understood across scales (Turner et al., 2003; O'Brien et al., 2004). 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.

5.5.2 Research needs for vulnerable fishery systems

Some fishery systems (coupled social-ecological systems) are shown to be particularly vulnerable 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).

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:

1. Adaptive Fisheries management in vulnerability hotspots

The vulnerability analysis undertaken by this project, despite limitations of data and method, have indicated potential vulnerability hotspots where fisheries and fishery-dependent communities face crises associated with multiple stressors, including climate-change. Low-lying island nations and countries with high fisheries dependency and low human development indices, for example, are shown to be particularly vulnerable and are likely to need major interventions. Low-lying atoll nations may be forced into adaptation strategies that involve long-term migration of human populations (Barnett and Adger, 2003). Diversification of nutritional sources may reduce vulnerability in other hotspots. Research on the impacts and feasibility of different policy and management adaptive responses is required for identified vulnerability hotspots. The outputs of this research would be transferable lessons on fisheries management for particularly vulnerable populations.

2. Vulnerability of the poor dependent on coral reef systems

Reef systems have been shown to be under considerable pressure from climate change, while also providing a wide range of ecological services (including fisheries) to the poor and vulnerable. These recommendations are based on the development and exploration of spatial and temporal statistical models of the relationships between environmental, ecological and social and economic parameters and the fish production.

- Measure the relative degree of dependence of fisherfolk on coral reefs for food and livelihoods among nations and regions.
- Devise and test measures of exposure and sensitivity of coral reef fisherfolk to climate change at national and regional scales and identify the basis of and scope for adaptive capacity and interventions.

- Explore the nature and degree to which coral reef fisheries production systems are exposed to, and sensitive to climate change and human population growth at regional and national scales
- Identification of poverty hotspots in coral reef countries at national scale
- What is the global, regional and national adaptive capacity of coral reef fisherfolk in terms of coral reef fish production, aquaculture and trade?

3. Resilience and vulnerability in Inland Fisheries

Although there is now a growing body of work on how inland fisheries systems respond to climate variation, both ecologically and in terms of livelihoods, there have been relatively few attempts to link the two at appropriate scales. The social and ecological resilience of some of these systems (e.g. floodplains, shallow lakes and wetlands) has often been argued, but the limits and threats to such resilience are little understood, leading to reluctance to abandon management practices that are based on the notion of some stability in productive capacity of the ecosystem and that may undermine resilience of either the ecological or the livelihood systems in the fishery.

Specific research needs include:

- Anticipated regional changes in river hydrology in response to climate change including predicted rainfall patterns, for major river basins. Inter and intra-annual changes to river discharge rates, flooding extent, duration and timing all have the potential to impact on fisheries and dependent livelihoods, but these data are seldom available.
- In relation to modelling the response of fish populations to changes in hydrological conditions, it is seen that whilst existing population models appear robust to assumptions
- Concerning density-dependence in growth, mortality and recruitment, density-independent influences are poorly understood at present. In particularly, how primary production changes in response to variation in hydrological conditions, and how this might affect key population processes, particularly recruitment.
- Focused field surveys of fisherfolk that have been identified as potentially the most vulnerable to climate change are required. A better understanding of the historic impacts of climatic variation on their fisheries and of their historic approaches to adaptation would provide a stronger basis for planning for future climatic changes.
- Understanding the dynamic interaction between capture and culture-based fisheries, aquaculture and farming on climate-change affected floodplain systems of south and south-east Asia. This would entail collaborative work with other NRSP programmes.

4. Climate-sensitive coastal small-scale fisheries

Fisheries for small-pelagic species that are fished by artisanal or small-scale fishing fleets, provide an important but unquantified contribution to global fisheries. They include the pirogue fisheries of West Africa and the purse-seine fleets of S and SE Asian coastal and shelf sea areas. Is climate change a significant risk factor in these fisheries? The impacts of climate change on major stocks of small-pelagic fish associated with upwelling systems are well-studied, but the smaller, more diverse stocks of coastal small pelagics (an assortment of clupeids and scombrids) are less-well studied, despite potentially sustaining more livelihoods and supplying more food to people (as opposed to fish meal for livestock and aquaculture industries). The research bias towards industrial-scale fisheries can be usefully drawn upon as a basis for comparative analysis of climate change impacts between large and small-scale sectors, by comparing, for example, the relative sensitivity and adaptive capacity of the commercial sector (more infrastructure and capital investment, less institutional resilience?) and the small-scale sector (less infrastructure-dependent, lower levels of capital investment, greater occupational mobility).

5. Interactions between fisheries exploitation and climate-driven variation.
The coral reef case study has highlighted the potentially negative reinforcing relationships between fishing pressure and climate change impacts, and this is an area requiring further research. Attempts to explore relationships between fish stock characteristics and patterns of fish biomass or catch variability (project R7113) could be extended to include correlation with climate-related factors.

6. Responses to changing levels of abundance
Although the role of fishery products in the global food system has been assessed through the World Fish Center's 'Fish to 2020' programme, no account has been taken of the possible impacts of future climate change on fish availability, price and therefore consumption patterns and preferences. Although classical economic theory suggests that scarcity and price increases lead to product substitution (e.g. chicken instead of fish), this does not take account of cultural preferences and their evolution. Consumer preferences and prices could modify the relationship between climate-induced changes in fish availability and fisherfolk's livelihoods. This is particularly pertinent for small-island states with strong fish-eating traditions, declining and climate-sensitive fisheries and growing populations.

5.5.3 Summary

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. Climate vulnerability assessment now requires work at field level, in partnership with the people and organisations that are likely to be affected by climate change and/or are in a position to respond strategically to the challenges it poses. Further synthesis and conceptual work is still required in this rapidly evolving field and dialogue with field research and implementation activities should be maintained. It is not just a case of now disseminating what is known; research and dissemination should be synergistic processes.

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 (Wigley, 2005; Meehl et al., 2005). 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 warming, rising and receding waters that the coming century will bring.

6 CONTRIBUTION OF OUTPUTS

6.1. Implications of outputs for DFID's development goals

DFID supports long-term programmes to help tackle the underlying causes of poverty and its work forms part of a global promise to contribute to the UN's eight 'Millennium Development Goals' with a 2015 deadline. This project aims to support DFID and its partners in working towards two goals in particular:

- halve the number of people living in extreme poverty and hunger
- make sure the environment is protected

The project will not lead to immediate implementable outputs but can be used to guide future research and policy formulation within DFID, FSMP and more broadly national governments, research institutions and international organisations. The project feeds into the UK government's commitment to address the causes and symptoms of global climate change, and the research outputs will help to design and target appropriate support to vulnerable natural-resource users and people living in the coastal and riparian zones of low-income countries.

Although the project originally also aimed to assess the 'nature, magnitude and time-scale of [climate-change] risks to livelihood sustainability', the analysis has in fact concentrated mainly on identifying the nature of potential impacts. It became clear during the analysis that our current level of knowledge is in most cases insufficient to assess the magnitude and time-scale of the risks, although this has been attempted for coral reef systems using a simple predictive linear regression model. Simulation models of river fisheries could not be used to establish magnitude of impact because of the complexity of interaction factors that may either increase or decrease fishery production and resource availability, such that it is not currently possible to predict with confidence whether fisheries from any given river will show a net increase or decrease under plausible climate change scenarios.

The project also originally specified that it would identify and propose 'mitigation strategies to support adaptive capacity of fisherfolk to cope with future climate change'. In the climate-change context, this was a misuse of the word 'mitigation', (Section 2.4). We have highlighted what is known about the adaptive nature of coastal and wetland livelihoods and directed attention to previous work on this subject but we felt that we were unable to add much to existing reviews in this area, and we were not able to conduct new analyses within the scope and budget of this study. There is a need for new empirical research in this area, which is suggested in Section 5, above. A summary of what is known about adaptive strategies will be included in outputs from a follow-up dissemination project (R8475).

6.2 Dissemination of research outputs to target institutions and beneficiaries

6.2.1. Target institutions

This research was initially intended to inform DFID responses to climate change impacts on fishing communities, principally through proposing a research agenda to guide those responses. This document has, however, gone a little further than that aim and has produced a good deal of original analysis, albeit in preliminary form. This report might also therefore find a readership among the target institutions for FMSP research outputs.

The target institutions for the research outputs include:

- Donor organisations involved in fisheries management and development in developing countries, e.g. DFID, FAO, World Fish Center
- Research organisations and members of the academic and policy-making communities involved in providing advice for fisheries management in developing countries e.g. Universities and natural resources research organisations
- Research organisations and members of the academic and policy communities involved in climate change research e.g. GLOBEC, IPCC.
- The research outputs have reached these target groups through the dissemination pathways detailed in the following sections.

6.2.2. Seminars/Workshops/Conferences

The research was presented by Marie-Caroline Badjeck at the International Conference: Climate Change and Aquatic Systems, Past, Present and Future' Plymouth, U.K., July 2004

6.2.3. Internal Technical Reports

In addition to this report, a summary version was submitted for DFID internal use in November 2004.

6.2.4. Publications

The following publications have been produced through this project:

Allison, E.H., and M-C. Badjeck (2004). Livelihoods, local knowledge and the integration of economic development and conservation concerns in the Lower Tana River Basin [invited comment]. *Hydrobiologia* **537:** 21-25.

Conway, D., Allison, E.H., Felstead, R. and Goulden, M. (2005). Rainfall variability in East Africa: implications for natural resources management and livelihoods. *Philosophical Transactions of the Royal Society A* **363:** 49-54.

6.2.5 Other dissemination pathways

The project is described on the School of Development Studies climate research group website: http://www.uea.ac.uk/dev/climate/impacts_3.htm

It was also mentioned in the 2004/5 Annual Newsletter of the School of Development Studies (http://www.uea.ac.uk/dev/newsletter/climate.htm) which reaches several thousand alumni all over the world.

6.3 Plans for future dissemination

It was never an objective of this project to disseminate the research widely within the lifetime of the project. Given the limited budget, it was primarily intended to provide an internal document for guidance of FMSP or its successor programmes on existing work on climate and fisheries. A follow-up dissemination project has already been commissioned and is ongoing at the time of writing (September 2005).

In addition to the activities planned under the follow-up project, future plans for dissemination during the next year include:

- Attendance and presentation of findings at the NERC/ESRC Interdisciplinary Seminar on Coastal and Marine Environmental Change, UCL, London (April 2005)
- Drafting of a policy brief on climate change and fisheries, in partnership with the FAO/DFID Sustainable Fisheries Livelihoods Programme, FAO, Rome. (September 2005)
- Two abstracts have been submitted to the Global Environmental Change – Human Dimensions Programme of the International Scientific Union, October 2005, Bonn, Germany.
- Submission of academic papers on global vulnerability assessment, review of pathways of impact, and on case studies on Coral Reef and Bangladesh floodplain climate, fisheries and livelihood vulnerability linkages.

6.4 Follow-up action and research

The anticipated follow-up actions are to continue to refine the analysis presented here and to disseminate the main findings of this research through a follow-up project funded through the Fisheries Management Science Programme. Funding for this follow-up project has been approved, subject to contract. It will be headed by the Centre for Environment, Fisheries and Aquaculture Sciences (CEFAS), one of the partners in this project, and will continue to involve members of the current research team, ensuring continuity of approach and further dissemination of outputs.

Future research will be guided by the research agenda outlined in Section 5.5. Addressing this research agenda will hopefully provide on-going attempts to assist governments, donors and other development partners, communities, households and individuals to respond appropriately to the challenges of strengthening fishing-based livelihoods in a time of climate change.

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ANNEX 1. DATA SOURCES AND VALUE CALCULATIONS FOR NATIONAL-LEVEL INDICES AND INDICATORS

This annex provides additional information on data sources and methods of deriving the indices used for the global vulnerability assessment methods.

Exposure Index:

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 abundance and distribution of fished species and through extreme events such as floods and storms affecting fishing operations and infrastructure), and less directly (e.g. through impacts on aquatic habitats, food supply, competitors, and predators and impacts on other production sectors that might affect peoples' livelihoods and food security, or impacts of change and extreme events on aspects of peoples lives not related to their fishing activities – diseases, impacts on their homes). These climate variables 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. Of these factors, however, temperature is both the most straightforward measure of climate change, and the best understood. For simplicity, we therefore used projected temperature change as a general proxy variable of climate change exposure.

Description: This indicator describes predicted increases in annual mean temperature by 2050.

Relevance: Projected temperature change is the most direct measure of future climatic change. The mechanisms underlying climate change effects on fisheries production are complex, varying depending on the particular region, ecosystem habitat, and stock of interest. Given the scale of our analyses, we have made the crude simplifying assumption that in areas where temperature increases are greater, relative impacts upon fisheries production will also be greater.

Measurement Units: degrees Centigrade (at 1.5m above the surface).
Year(s) of coverage: 2050 (scaled values based on projected increases for 2080)
Source(s): This variable is taken from the TYN CY 3.0 dataset compiled by Mitchell et al. (2003).

Methodology: Projections 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 A1.1). Country-specific values were derived by Mitchell et al. (2003), based on gridded values from 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 A1.1 A summary of the four main scenarios in the Special Report on Emissions Scenarios (SRES), published by the Intergovernmental Panel on Climate Change (IPCC).

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.

Notes:

- Caveats regarding the use of the TYN CY 3.0 data are described by Mitchell (2003).
- The IPPC are producing a new assessment in 2005.

Construction of Sensitivity Index:

The sensitivity index aims to understand the degree to which fisheries production systems are affected by climate change, taking into account their inherent characteristics. The index aimed to assess how “sensitive” countries would be to climate change by understanding their relative dependency on fisheries production systems in terms of food security, economic dependency, and number of fishermen involved in the activity. Additionally, DFID/FMSP programmes target poor fisherfolk around the world; hence the study wanted the index to reflect areas where there was a high number of poor fisherfolk. The variables used to create the sensitivity index are described below.

Index related to number of fisherfolk living in poverty

Description: The index of poorest fisherfolk is a composite indicator of the number of fisherfolk per country and the income per capita (GDP per capita).

Relevance: One of the aims of the project is to identify not only vulnerable areas to human-induced climate change, but also areas where poor fishing communities are located.

Measurement Units: Per capita GDP in US dollars and numbers of individuals

Year(s) of coverage: 1996 for the number of fisherfolk and 2003 for GDP/capita

Source(s): FAO Fishery Information, Data and Statistics Unit "Numbers of Fishers 1970-1996" FAO Fisheries Circular No.929, Rev 1. 1999. 124p. FAO: Rome.
United Nations Statistics Division, 2004. “National Accounts Main Aggregates Database”. URL: http://unstats.un.org/unsd/snaama/Introduction.asp

Methodology: Both variables where indexed, then averaged with equal weighting. For GDP per capita the index was transformed to [100-Index Value] so that the highest index reflects the lowest GDP/capita (i.e. highest value = the most poor country)

Notes: In the absence of available data for the number of poor fisherfolk (or indeed for a national poverty headcount – not available for a lot of countries) we chose to use the inverse of GDP per capita as a poverty indicator to combine with the overall number of fisherfolk.

FAO recognises the relative inaccuracy of its data on numbers of fishers. The CWP noted a number of problems in identifying and enumerating separately "fishers" as primary producers or agriculture-sector workers among the economically active population. These problems arise largely from the seasonal availability of the various fishery resources compounded by the seasonal availability of more lucrative occupations (CWP, 2004). Another problem is associated with subsistence fishing which is undertaken on a full-time, part-time, or occasional basis in many developed or developing communities as part of the occupation of the economically-active populations. However, people who are too young, too old to be normally included in the economically active population may be involved in subsistence fishing. These issues are further complicated where subsistence fishing merges with recreational fishing (CWP, 2004)

For more information on these issues see FIDI-FAO, CWP Handbook of Fishery Statistical Standards, 2004. URL: http://www.fao.org/figis/servlet/static?dom=root&xml=ontology/cwp/index.xml)

FAO circular No 929 rev.2 was not available at the time this analysis was done, and is not available electronically outside FAO, meaning that the older values from rev 1 were used in this analysis.

Table A1.1 presents the classification of the data into quartiles, with the coloured shading illustrating quartiles that the data fall into, while Table A1.2 presents all the country values for the index representing poverty and numbers of small scale fisherfolk.

Table A1.1 Legend showing classification of data into quartiles

	Lowest	
	Medium-Lowest	
	Medium- Highest	
	Highest	
MV	**no data**	Missing values

Table A1.1 Index of poverty and numbers of fisherfolk by country

Final Country List	Indices-poorest fisherfolk Ranked	Final Country List	Indices-poorest fisherfolk Ranked	Final Country List	Indices-poorest fisherfolk Ranked	Final Country List	Indices-poorest fisherfolk Ranked	Final Country List	Indices-poorest fisherfolk Ranked	Final Country List	Indices-poorest fisherfolk Ranked	Final Country List	Indices-poorest fisherfolk Ranked	Final Country List	Indices-poorest fisherfolk Ranked
American Samoa	MV	China	99.02	Liberia	49.93	Papua New Guinea	49.59	Tonga	48.53	Jamaica	47.42	Palau	44.14	Cyprus	34.64
Anguilla	MV	India	74.22	Rwanda	49.92	Iraq	49.56	Russian Federation	48.48	Venezuela	47.36	Croatia	44.13	New Caledonia	33.95
British Virgin Islands	MV	Indonesia	68.50	Zimbabwe	49.91	Sri Lanka	49.55	Kazakhstan	48.43	Turkmenistan	47.12	Estonia	44.12	China, Macao SAR	33.72
Cayman Islands	MV	VietNam	62.17	Niger	49.90	Lesotho	49.51	Cape Verde	48.40	Saint Vincent/Grenadines	47.07	Oman	43.07	French Polynesia	32.83
Faeroe Islands	MV	Bangladesh	55.69	Guinea-Bissau	49.89	Angola	49.51	Belarus	48.40	Uruguay	46.94	Cook Islands	43.02	Israel	32.65
Falkland Is.(Malvinas)	MV	Philippines	53.22	Gambia	49.87	Nicaragua	49.42	Samoa	48.38	Dominica	46.93	Trinidad and Tobago	42.81	New Zealand	31.46
French Southern Terr	MV	Nigeria	51.52	Eritrea	49.85	Cameroon	49.41	Jordan	48.35	Turkey	46.93	Hungary	42.02	Spain	30.75
Greenland	MV	Kenya	51.46	Tajikistan	49.84	Kiribati	49.41	Serbia and Montenegro	48.31	Argentina	46.88	Saudi Arabia	41.93	Aruba	30.72
Guam	MV	Myanmar	51.36	Burkina Faso	49.83	Georgia	49.35	Guatemala	48.30	Belize	46.85	Seychelles	41.60	Puerto Rico	30.04
Mayotte	MV	Pakistan	51.26	Haiti	49.81	Côte d'Ivoire	49.31	Albania	48.24	Panama	46.85	Czech Rep	41.58	Singapore	29.67
Moldova, Rep	MV	Chad	51.25	Benin	49.80	Bolivia	49.27	Algeria	48.21	Nauru	46.75	Saint Kitts and Nevis	41.49	United Arab Emirates	28.82
Monaco	MV	Nepal	50.95	Zambia	49.80	Azerbaijan	49.27	Peru	48.19	South Africa	46.71	Antigua and Barbuda	41.38	China, Hong Kong SAR	28.41
Mongolia	MV	Ghana	50.70	Lao People's Dem Rep	49.80	Colombia	49.23	Thailand	48.07	Libyan Arab Jamahiriya	46.62	Korea, Rep	40.85	Italy	25.66
Montserrat	MV	Congo, Dem Rep	50.39	Bhutan	49.79	Djibouti	49.23	Marshall Islands	48.07	Malaysia	46.43	French Guiana	40.74	Australia	24.60
Niue	MV	Madagascar	50.37	Central African Rep	49.79	Egypt	49.23	Maldives	48.00	Botswana	46.26	Barbados	40.59	Canada	24.33
Northern Mariana Is.	MV	Korea, Dem People's Rep	50.14	Togo	49.79	Armenia	49.21	Macedonia, FYR	47.97	Gabon	46.10	Malta	38.73	France	22.04
Palestine, Occupied Tr.	MV	Cambodia	50.14	Uzbekistan	49.78	Honduras	49.21	El Salvador	47.96	Costa Rica	46.06	Bahrain	38.02	Germany	22.04
Pitcairn Islands	MV	Malawi	50.11	Comoros	49.76	Paraguay	49.14	Suriname	47.94	Chile	46.06	Brunei Darussalam	37.65	Belgium	21.90
Saint Helena	MV	Mali	50.09	Solomon Islands	49.75	Guyana	49.13	Micronesia, Fed.States of	47.89	Grenada	45.98	Netherlands Antilles	37.31	United Kingdom	20.92
Slovakia	MV	Tanzania, United Rep	50.08	Mauritania	49.74	Morocco	49.12	Tuvalu	47.88	Latvia	45.81	Kuwait	36.95	Finland	20.18
Swaziland	MV	Burundi	50.06	Sao Tome and Principe	49.74	Congo	49.08	Namibia	47.87	Mauritius	45.70	Slovenia	36.76	Austria	20.05
Taiwan Province of China	MV	Uganda	50.03	Sudan	49.74	Vanuatu	48.99	Tunisia	47.87	Saint Lucia	45.65	Bahamas	36.20	Netherlands	19.50
Timor-Leste	MV	Somalia	50.01	Kyrgyzstan	49.72	Ecuador	48.73	Dominican Rep	47.82	Mexico	45.42	Martinique	36.12	Japan	18.69
Tokelau	MV	Ethiopia	50.01	Guinea	49.72	Brazil	48.68	Fiji	47.67	Lebanon	45.28	Guadeloupe	36.10	Sweden	17.40
Turks and Caicos Is.	MV	Sierra Leone	49.96	Senegal	49.72	Syrian Arab Rep	48.67	Romania	47.65	Lithuania	45.09	Portugal	36.09	Qatar	16.68
US Virgin Islands	MV	Mozambique	49.94	Yemen	49.67	Bosnia and Herzegovina	48.54	Bulgaria	47.65	Poland	44.96	Réunion	36.01	United States	15.71
Wallis and Futuna Is.	MV	Afghanistan	49.93	Ukraine	49.64	Iran, Islamic Rep	48.53	Cuba	47.47	Equatorial Guinea	44.40	Greece	35.06	Iceland	15.11
														Ireland	12.68
														Denmark	12.06
														Switzerland	8.19
														Norway	3.11
														Bermuda	0.001

Index of Economic dependency on the fisheries sector

Description: This composite indicator comprises the value of fish exports and re-exports as a percentage of value of total exports of good and services, the number of fisherfolk as a percentage of the economically active population (EAP), and total catches or landings.

Relevance: This indicator attempts to quantify and describe the socio-economic importance of fishing as well as determine the level of dependency on fisheries of these areas, in terms of jobs (percent of the economic active population) and incomes at the national level (exports). Landings data add a biological production component to the index. The choice of variables was also restricted by the availability of data for a global scale analysis.

Measurement Units: Total catch in metric tons (t), Export values in millions US dollars at 1998-2001 average values, fisherfolk as a percentage of the EAP

Year(s) of coverage: For catches 1998-2002 average, for exports 1998-2001 average, EAP in 2000 and number of fisherfolk in 1996.

Source(s):

FAOSTAT, 2004. "Long-term Series (decennial) Agricultural Population & Economically Active Population" FAO: Rome.
URL: http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0

Value of total exports in millions of dollars averaged for 1998-2001 from Development Data Group, The World Bank. 2003. World Development Indicators 2003 Online, Washington, D.C.: The World Bank.
URL: http://publications.worldbank.org/ecommerce/catalog/product?item_id=631625

Fish export and fish catch data were obtained from the FAO Fisheries Department, Fisheries Information, Data and Statistics Unit: FISHSTAT Plus - Universial software for fishery statistical time series. Version 2.3, http://www.fao.org/fisheries/

Hardcopy versions of this data are available at:

FAO, 2002a. FAO Yearbook, Fishery Statistics, Commodieites, 2002, Vol 95.
FAO, 2002b. FAO Yearbook. Fishery Statistics. Capture production 2002, Vol 94/1

Methodology:

Total economic active population data was extracted from FAOSTAT then the percentage of fisherfolk for the EAP was calculated. The EAP data are from 2000 and the number of fisherfolk data are for 1996, so all values will tend to be underestimates, as the EAP would have increased in size over the four years that separates the two values, while the relative rate of increase in number of fisherfolk during the same period is unknown. FAO (2004) suggest that the rapid increase in the numbers of fisherfolk evident in the period 1950 – 1990 have since slowed or stopped, particularly in Asia, where most of the world's fisherfolk are found.

Trade values were compiled from FAO fisher statistics (FAO 2002a) using FishSTAT (FAO, 2000). Export and re-export values were summed. In order to foucs on the importance of fisheries to food supply, we included only products fit for human consumption. Therefore, trade values excluded primary or processed products of algae, aquatic mammals, corals, cuttlefish bones, fish waste, shells, sponges or other products unfit for human consumption.

Fisheries production quantitites were similarly compiled from FAO fishery statistics (FAO 2002b) using FishSTAT (FAO, 2000). Quantities were summed across capture fisheries for coastal and inland waters. Again focusing on food fisheries, we excluded algae, amphibians, aquatic mammals, corals, reptiles, shells and sponges.

The three obtained variables were then indexed and averaged (equally weighted); they are presented in Table A1.3.

Notes:
Total Economically Active Population

This refers to the number of all employed and unemployed persons (including those seeking work for the first time). It covers employers; self-employed workers; salaried employees; wage earners; unpaid workers assisting in a family, farm or business operation; members of producers' cooperatives; and members of the armed forces.

It is worth noting that for regional and country level studies other or more accurate variables could be used (See ADB report "The Contribution of Fisheries to the Economies of Pacific Island Countries" which could be used for regional modelling).
http://www.adb.org/Documents/Reports/Contribution_Fisheries_Pacific_Economies/default.asp

For ecosystem-based assessments, the Sea Around Us Project (www.seaaroundus.org) has compiled landings on the basis of Large Marine Ecosystem Units, rather than countries or regional statistical units.

China's fishery statistics are widely regarded as overestimates (Watson and Pauly, 2001) and FAO now routinely present global fishery statistics 'with and without' China. Given China's apparent dominance of world fisheries, poverty headcounts and exposure to climate change when it is included, this distinction could be made in future analyses of this type.

Table A1.2 Economic Dependency Index by country (overleaf)

Final Country	IEDFS	Country	IEDFS	Country	IEDFS	Country	IEDFS	Country	IEDFS	Country	IEDFS	Country	IEDFS	Country	IEDFS
Afghanistan	MV!	Mayotte	MV!	Turks and Caicos Is.	MV!	United States	9.825	Kenya	3.197	Colombia	1.857	Lithuania	1.027	Saudi Arabia	0.300
American Samoa	MV	Moldova, Rep	MV	Tuvalu	MV	India	9.574	Spain	3.180	Costa Rica	1.853	Guatemala	1.018	Dominican Rep	0.267
Anguilla	MV	Monaco	MV	United Arab Emirates	MV	Russian Federation	8.899	Cambodia	3.166	Trinidad and Tobago	1.774	Sweden	1.014	Congo	0.262
Aruba	MV	Mongolia	MV	US Virgin Islands	MV	Morocco	8.234	Canada	3.017	Benin	1.703	Malta	0.996	Belgium	0.250
Bahamas	MV	Montserrat	MV	Vanuatu	MV	Palau	8.072	Saint Vincent/Gre nadines	2.955	Antigua and Barbuda	1.602	China, Hong Kong SAR	0.993	Sudan	0.249
Bermuda	MV	Myanmar	MV	Wallis and Futuna Is.	MV	Nicaragua	7.927	Cape Verde	2.901	Saint Lucia	1.568	Angola	0.939	Singapore	0.232
Bhutan	MV	Nauru	MV	Iceland	39.379	Belize	7.174	Libyan Arab Jamahiriya	2.862	Nepal	1.563	Egypt	0.923	Paraguay	0.221
British Virgin Islands	MV	Netherlands Antilles	MV	China	35.329	Philippines	6.611	Côte d'Ivoire	2.856	Nigeria	1.557	Poland	0.903	Botswana	0.216
Brunei Darussalam	MV	Niue	MV	Marshall Islands	34.688	Bangladesh	6.566	Pakistan	2.748	Venezuela	1.490	Albania	0.875	Belarus	0.206
Cayman Islands	MV	Northern Mariana Is.	MV	Peru	24.774	Chad	6.478	Estonia	2.728	Netherlands	1.475	Italy	0.769	Kuwait	0.195
China, Macao SAR	MV	Oman	MV	Seychelles	22.075	Panama	6.431	Mauritius	2.581	France	1.460	Congo, Dem Rep	0.751	Bolivia	0.159
Cook Islands	MV	Palestine, Occupied Tr.	MV	Mauritania	21.308	Denmark	6.115	Sri Lanka	2.488	Barbados	1.397	Jamaica	0.712	Azerbaijan	0.157
Cuba	MV	Pitcairn Islands	MV	Sao Tome and Principe	19.162	Tanzania, United Rep	5.940	Uruguay	2.455	Portugal	1.353	Haiti	0.645	Bosnia and Herzegovina	0.128
Faeroe Islands	MV	Puerto Rico	MV	Maldives	18.246	Guyana	5.820	Micronesia, Fed.States of	2.452	Australia	1.318	Malawi	0.602	Bulgaria	0.128
Falkland Is.(Malvinas)	MV	Qatar	MV	Samoa	17.197	Korea, Rep	5.262	Honduras	2.430	El Salvador	1.265	Macedonia, FYR	0.590	Zimbabwe	0.126
French Guiana	MV	Réunion	MV	Senegal	16.188	Guinea-Bissau	4.808	Suriname	2.344	Turkey	1.252	Germany	0.581	Burkina Faso	0.108
French Southern Terr	MV	Rwanda	MV	Chile	15.174	Uganda	4.597	Papua New Guinea	2.242	Eritrea	1.232	Zambia	0.520	Syrian Arab Rep	0.093
Greenland	MV	Saint Helena	MV	Ecuador	14.956	Ghana	4.521	Equatorial Guinea	2.216	Togo	1.232	Lebanon	0.518	Czech Rep	0.087
Guadeloupe	MV	Slovakia	MV	Namibia	14.268	Grenada	4.326	Latvia	2.150	Ukraine	1.230	Cameroon	0.510	Hungary	0.086
Guam	MV	Solomon Islands	MV	Fiji	13.967	New Zealand	4.173	Saint Kitts and Nevis	2.120	Gabon	1.222	Burundi	0.508	Georgia	0.082
Iraq	MV	Somalia	MV	VietNam	13.729	Argentina	4.152	Croatia	1.995	Ireland	1.216	Niger	0.491	Romania	0.079
Kiribati	MV	Swaziland	MV	Indonesia	13.289	New Caledonia	3.767	Tunisia	1.974	Gambia	1.205	Finland	0.491	Djibouti	0.076
Korea, Dem People's Rep	MV	Taiwan Province of China	MV	Mozambique	12.737	Dominica	3.686	Brazil	1.973	Greece	1.188	Lao People's Dem Rep	0.432	Armenia	0.062
Kyrgyzstan	MV	Tajikistan	MV	Sierra Leone	11.309	French Polynesia	3.391	Guinea	1.946	Yemen	1.182	Cyprus	0.391	Israel	0.058
Lesotho	MV	Timor-Leste	MV	Norway	10.373	Malaysia	3.352	South Africa	1.917	Iran, Islamic Rep	1.155	Algeria	0.389	Slovenia	0.054
Liberia	MV	Tokelau	MV	Japan	10.105	Mexico	3.320	Comoros	1.881	Bahrain	1.125	Central African Rep	0.329	Turkmenistan	0.053
Martinique	MV	Tonga	MV	Thailand	10.043	Madagascar	3.206	United Kingdom	1.859	Mali	1.040	Kazakhstan	0.314	Austria	0.043
														Jordan	0.041
														Uzbekistan	0.038
														Serbia and Montenegro	0.035
														Ethiopia	0.035
														Switzerland	0.009

IEDFS = Index of economic dependency on the fisheries sector

Index of nutritional dependency

Description: Nutritional dependency identifies countries reliant on fish as a primary source of animal protein. This is expressed by fish as a source of protein (g) as the percentage of all animal protein sources (g) consumed per capita per day.

Relevance: The importance of the fisheries sector in terms of food security, nutrition. The importance of supply balance sheets for assessing the per caput supply and the degree of self-sufficiency in fishery products of in particular low-income food-deficit countries is stressed.

Measurement Units: Both fish and animal protein sources are measured as grammes of product consumed per person per day, so, assuming similar protein content of fish and other animals, the values calculated are simply expressed as a percentage.

Year(s) of coverage: Average 1998-2001

Source(s): FAOSTAT, 2004. "Food Balance Sheets". URL: http://faostat.fao.org/faostat/form?collection=FBS&Domain=FBS&servlet=1&hasbulk=0&version=ext&language=EN

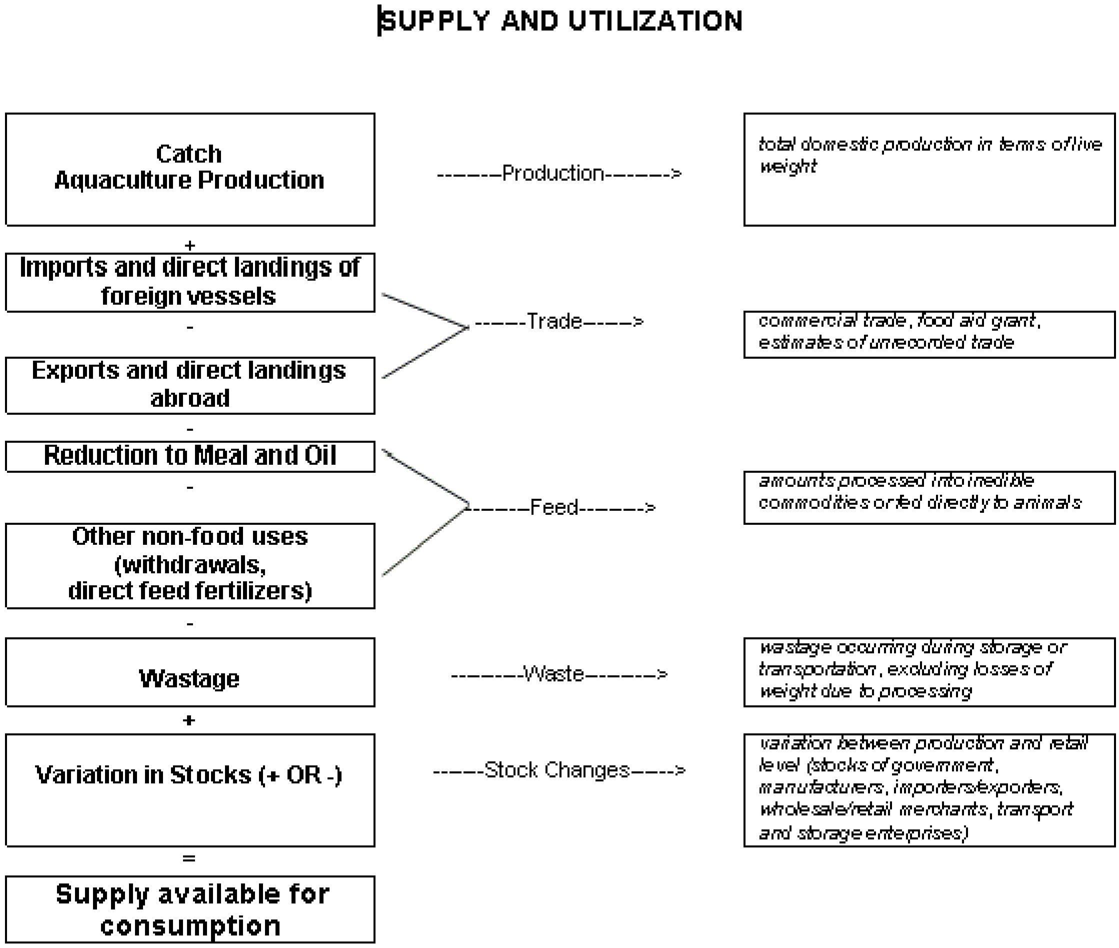
Methodology: We first extracted from FAO food balance sheets the supply of fish protein per capita per day in grams for all countries, derived by FAO, by dividing the total supply of food fish (Production + Imports – exports) by the national population. We similarly obtained the total supply of animal protein per capita per day (g) and used the two measures to establish the supply of fish protein as a percentage of all animal protein.

Notes: A food balance sheet presents a comprehensive picture of the pattern of a country's food supply during a specified reference period (for more information see http://www.fao.org/waicent/faostat/agricult/fbs-e.htm).

It is important to note that we were unable to separate data related to aquaculture production. In food balance sheets production figures cover catch and culture of all fish, crustaceans, molluscs and aquatic organisms, excluding mammals and aquatic plants. Figure A1.1, overleaf, presents how national average fish consumption is established by FAO.

The food balance sheet shows for each food item - i.e. each primary commodity and a number of processed commodities potentially available for human consumption - the sources of supply and its utilization. The total quantity of foodstuffs produced in a country added to the total quantity imported and adjusted to any change in stocks that may have occurred since the beginning of the reference period gives the supply available during that period. On the utilization side a distinction is made between the quantities exported, fed to livestock, used for seed, put to manufacture for food use and non-food uses, losses during storage and transportation, and food supplies available for human consumption. The per caput supply of each such food item available for human consumption is then obtained by dividing the respective quantity by the related data on the population actually partaking of it. Data on per caput food supplies are expressed in terms of quantity and - by applying appropriate food composition factors for all primary and processed products - also in terms of calorific value and protein and fat content.

Figure A1.1 National average fish consumption using Food Balance sheets.



Summary of procedure for estimation of national average fish consumption by means of **Food Balance Sheets**.

Source: FIDI-FAO, CWP Handbook of Fishery Statistical Standards, 2004. URL: http://www.fao.org/figis/servlet/static?dom=ontology&xml=cwp/sectionP.xml&xsl=webapps/figis/wwwroot/fi/figis/ontology/cwp/format_static/handbook.xsl

Final Country List	Index - Nutritional dependency	Final Country List	Index - Nutritional dependency	Final Country List	Index - Nutritional dependency	Final Country List	Index - Nutritional dependency	Final Country List	Index - Nutritional dependency	Final Country List	Index - Nutritional dependency	Final Country List	Index - Nutritional dependency	Final Country List	Index - Nutritional dependency
Afghanistan	MV	Nauru	MV	Sierra Leone	72.285	Lao People's Dem Rep	38.933	Bermuda	23.250	United Arab Emirates	13.571	Nicaragua	9.692	Brazil	4.833
American Samoa	MV	Niue	MV	Kiribati	71.893	Papua New Guinea	38.320	Yemen	22.966	Bahamas	13.528	Ecuador	9.270	Austria	4.791
Anguilla	MV	Northern Mariana Is.	MV	Gambia	69.438	Cameroon	38.131	Burundi	22.738	Dominican Rep	13.515	Panama	8.848	Moldova, Rep	4.721
Aruba	MV	Oman	MV	Indonesia	67.882	Angola	36.438	Spain	21.312	Ukraine	13.506	Zimbabwe	8.792	Botswana	4.593
Bahrain	MV	Palau	MV	Sri Lanka	61.992	Malawi	36.381	Venezuela	20.296	Greece	12.985	Iran, Islamic Rep	8.466	Belarus	4.466
Bhutan	MV	Palestine, Occupied Tr.	MV	Sao Tome and Principe	59.870	Liberia	35.379	Brunei Darussalam	19.778	Namibia	12.884	Mexico	8.071	Nepal	4.388
British Virgin Islands	MV	Pitcairn Islands	MV	Bangladesh	58.456	Tanzania, United Rep	35.375	Madagascar	19.729	Italy	12.787	Germany	7.950	Niger	4.358
Cayman Islands	MV	Puerto Rico	MV	Seychelles	56.181	Korea, Dem People's Rep	35.298	Grenada	19.714	Poland	12.729	United States	7.931	Paraguay	4.284
China, Hong Kong SAR	MV	Qatar	MV	Togo	55.235	Iceland	34.874	Saint Lucia	19.404	Kenya	12.670	Libyan Arab Jamahiriya	7.828	Argentina	4.240
China, Macao SAR	MV	Réunion	MV	Guinea	54.940	Cape Verde	32.245	Morocco	19.328	Haiti	12.520	Switzerland	7.767	Slovenia	3.896
Cook Islands	MV	Saint Helena	MV	Guyana	54.367	Norway	30.448	Cuba	18.529	Latvia	12.393	Australia	7.692	Guatemala	3.687
Equatorial Guinea	MV	Samoa	MV	Congo	53.590	Suriname	29.713	Mali	17.425	Cyprus	12.302	Algeria	7.128	Pakistan	3.682
Faeroe Islands	MV	Singapore	MV	Japan	52.280	Zambia	27.232	Chad	17.383	Canada	11.673	Croatia	7.068	Bulgaria	3.504
Falkland Is.(Malvinas)	MV	Somalia	MV	Cambodia	51.969	Benin	26.606	Belize	17.362	Mauritania	11.434	Saudi Arabia	7.027	Djibouti	3.116
French Guiana	MV	Taiwan Province of China	MV	Myanmar	51.625	Portugal	26.604	Finland	16.726	United Kingdom	11.215	Burkina Faso	7.020	Honduras	2.926
French Southern Terr	MV	Tajikistan	MV	Congo, Dem Rep	51.454	Antigua and Barbuda	26.519	Russian Federation	16.524	Netherlands Antilles	11.208	Ireland	6.443	Syrian Arab Rep	2.861
Greenland	MV	Timor-Leste	MV	Senegal	51.297	Mauritius	26.057	Sweden	16.105	Swaziland	11.166	Lebanon	6.356	Bosnia and Herzegovina	2.843
Guadeloupe	MV	Tokelau	MV	Philippines	48.665	Mozambique	25.883	Trinidad and Tobago	16.066	Denmark	11.130	Kuwait	6.143	Hungary	2.550
Guam	MV	Tonga	MV	Côte d'Ivoire	46.909	Dominica	25.875	New Caledonia	15.887	Netherlands	11.080	Slovakia	6.076	Turkmenistan	2.224
Iraq	MV	Turks and Caicos Is.	MV	Korea, Rep	46.890	French Polynesia	25.782	Lithuania	15.814	Chile	10.871	Eritrea	6.038	Sudan	2.114
Lesotho	MV	Tuvalu	MV	Thailand	45.732	Fiji	25.444	Malta	15.785	Turkey	10.715	Jordan	5.661	Romania	2.098
Marshall Islands	MV	US Virgin Islands	MV	Gabon	43.537	Egypt	24.715	India	15.627	Central African Rep	10.431	Czech Rep	5.632	Albania	2.086
Martinique	MV	Wallis and Futuna Is.	MV	Malaysia	43.516	Barbados	24.170	New Zealand	15.364	France	10.218	Colombia	5.359	Bolivia	2.066
Mayotte	MV	Maldives	100.000	Vanuatu	41.980	Jamaica	24.167	Saint Vincent/Grenadines	15.129	Belgium	9.903	Costa Rica	5.202	Georgia	1.870
Micronesia, Fed.States of	MV	Solomon Islands	95.395	Nigeria	40.462	Saint Kitts and Nevis	23.631	Tunisia	14.284	Rwanda	9.900	Macedonia, FYR	5.162	Ethiopia	1.857
Monaco	MV	Ghana	79.221	VietNam	39.630	Peru	23.449	Estonia	14.182	South Africa	9.810	El Salvador	5.124	Kazakhstan	1.638
Montserrat	MV	Comoros	73.200	Uganda	39.129	China	23.407	Guinea-Bissau	13.784	Israel	9.726	Uruguay	4.922	Serbia and Montenegro	1.555
														Azerbaijan	1.278
														Armenia	0.693
														Kyrgyzstan	0.578
														Uzbekistan	0.522
														Mongolia	0.000

Table A1.4 Index of nutritional dependency on fish, by country

Potential Impact Index:

The sensitivity and exposure indices were averaged to obtain the potential impact index.

Adaptive Capacity Index:

Indicators of adaptive capacity are difficult to identify. At the national level, adaptive capacity has been shown to be strongly related to factors such as health, literacy and governance (Brooks et al., 2004). Additionally Gross Domestic Product (GDP) was added as an indicator to reflect the fact that the size of the economy can play a role in adaptive capacity.

For the construction of the adaptive capacity index, the Climate Analysis Indicator Tool (CAIT) of the World Resources Institute (WRI) was used. The CAIT, available on the web at http://cait.wri.org, provides a comprehensive and comparable database of climate-relevant indicators. The CAIT also includes seven analysis features, among them the ability to combine indicators into an aggregate index. We used the latter to create the adaptive capacity index. We then reversed the index values by using [100 – index - value] to ensure that high index values indicate high vulnerability (i.e. the United States who had the highest adaptive capacity in CAIT are at the bottom of our table, high index values corresponding to low level of adaptive capacity). Below, each indicator is described according to the CAIT 'Indicator Framework Paper' (http://cait.wri.org/downloads/framework_paper.pdf).

Health Index

Description: Healthy life expectancy (HALE) is based on life expectancy, but includes an adjustment for time spent in poor health. This indicator measures the equivalent number of years in full health that a newborn child can expect to live based on the current mortality rates and prevalence distribution of health states in the population.

Relevance: According to the World Health Organization, life expectancy provides a useful indicator of the overall health effects of environmental and other risk factors in a given population. The link between health and climate protection is one of opportunity cost. Countries with significant public health problems (and related societal consequences like those mentioned above) are likely to find it socially and politically difficult to allocate resources to climate protection. The opportunity costs of devoting scarce resources to climate change mitigation may be high in such countries.

Measurement Units: Years

Year(s) of coverage: 2001

Source(s): WHO. World Health Report 2002: Reducing Risks, Promoting Healthy Life. Geneva. Available at: http://www.who.int/whr/2002/en/
For HALE data, see: http://www.who.int/whr/2002/en/whr2002_annex4.pdf

Methodology: Data downloaded from CAIT software available at http://cait.wri.org/downloads.php

Notes: Healthy life expectancy is influenced by a wide range of factors, including air quality, access to clean water and sanitation, shelter, the prevalence of disease (e.g., AIDS, malaria, and tuberculosis), and occupational health risks among others. Overall, in adjusting life expectancy, HALE estimates account for 135 disease and injury causes. The figures reported by WHO along with the data collection and estimation methods have been largely developed by WHO and do not necessarily reflect official statistics of Member States.

Education Index

Description: Education levels are measured by adult literacy rates and school enrolment. WRI has calculated a simple education index that includes literacy and enrolment data, following the methodology used by UNDP (2003) in calculating the Human Development Report's education index. Adult literacy is the percentage of people aged 15 and above who, with understanding, can read and write a short, simple statement on their everyday life. The gross enrolment ratio is the number of students enrolled in a level of education, regardless of age, as a percentage of the population of official school age for that level. The ratio used in CAIT is a combination of primary, secondary, and tertiary gross enrolment.

Relevance: Countries with higher levels of education are likely to have higher adaptive and mitigative capacity. Like income, this is supported by the determinants of adative capacity discussed above. Most specifically, education levels speak to a country's stock of human capital. Those countries with higher levels of educational attainment are likely to have more skilled staff to undertake important functions related to climate protection, including skills for implementing low carbon technologies, carrying out economic assessments and greenhouse gas accounting, information management systems, and an array of other activities.

Measurement Units: (1) Literacy: % of people ages 15 and above. (2) Enrolment: Combined Primary, Secondary, and Tertiary Gross Enrolment Ratio (%).

Year(s) of coverage: 2000/2001

Source(s): UNDP 2003. Original Source: UNESCO

Methodology: In calculating a simple education index, CAIT has followed the methodology used by UNDP (2003) in calculating the Human Development Report's education index. Accordingly, they have assigned a weight of two-thirds to the literacy rates, and a weight of one-third to the enrolment ratios to generate the aggregate education index.

Notes: The literacy data used measures only basic reading and writing ability. To provide a more accurate measure of adaptive and mitigative capacity, a more nuanced measure of educational achievement is needed. Literacy "proficiency tests," for example, assess a range of reading and writing skills and are able to distinguish a spectrum of literacy levels, thus providing a finer measure of how well adults use information to function in society. Unfortunately, no such data currently exist that are globally comprehensive. In the absence of a fine grained measure of educational achievement levels, we have used UNDP's measure as a reasonable proxy.

Governance Index

Description: This indicator attempts to capture the complex and multifaceted aspects of governance as a composite index based on six dimensions of governance: (1) political stability (e.g., perceptions of the likelihood of armed conflict); (2) government effectiveness (e.g., bureaucratic quality); (3) regulatory quality (e.g., regulatory burden, market-friendliness); (4) rule of law (e.g., black markets, enforceability of contracts); (5) voice and accountability (e.g., free and fair elections, political rights); and (6) corruption (e.g., prevalence among public officials). Each of these dimensions is weighted equally in this indicator. This governance indicator, devised by the World Bank, draws on 17 separate sources of subjective data on perceptions of governance constructed by 15 organizations.

Relevance: Although some more than others, all dimensions of governance are relevant to mitigative capacity. The dimensions of governance captured in this indicator are especially linked to determinants 3 (institutions and decision-making authority), 6 (social capital), and 7 (information). Political instability or inability to exercise regulatory control over domestic entities, for example, might be barriers to the adoption and implementation of new technological options (determinant 1) and policies (determinant 2). Higher levels of "voice and accountability" might open up political space for NGOs and other interest groups to demand government actions on climate change.

Measurement Units**:** An indicator with no units

Year(s) of coverage: 2000/2001

Source(s): Kaufmann et al. 2002 (World Bank). Kaufmann, D., A. Kraay, and P. Zoido-Lobatón. 2002. *Governance Matters II: Updated Indicators for 2000/01*. Policy Research Working Paper 2772. Washington, DC: The World Bank. URL: http://www.worldbank.org/wbi/governance/pubs/govmatters3.html

Methodology & Notes: Many indicators attempt to gauge the effectiveness of governments and the extent of democratic institutions (see, e.g., UNDP 2002: 36). Because of the complex nature of governance, a single indicator, whether objective (e.g., number of NGOs) or subjective (e.g., government stability) is unlikely to capture the wide range of relevant concepts. The World Bank has developed governance indicators in a wide variety of areas for most countries and combined them into composite indices. These indices cover six dimensions of governance mentioned above (Kaufmann et al. 2002).

The governance indicator used in CAIT is qualitatively different than the other indicators described in this section. Namely, governance is measured by a subjective indicator, whereas the others are objective indicators. The World Bank (and others, see UNDP 2002: 37) governance indicators draw on 17 separate sources of subjective data on perceptions of governance constructed by 15 different organizations (Kaufmann et al. 2002). The Bank points out that: "the margins of error associated with the composite estimates of governance for each country are typically quite large relative to the units in which governance is measured. This implies that cross-country comparisons of the quality of governance based on this type of data need to be made with considerable caution: many of the small measured differences in governance perceptions are too small to be statistically—or practically—significant, and only large differences are likely to be statistically meaningful."

Size of Economy Index

Description: Gross domestic product (GDP) is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. There are two GDP indicator included in CAIT: income per capita (i.e., GDP per capita) and size of economy (i.e., total GDP). Both are measured in purchasing power parity (PPP).

Relevance: Size of economy itself is a function of other variables, especially population. Those countries with larger economies are likely to have larger amounts of aggregate financial resources than smaller economies, all other things being equal. The larger an economy is, the larger may be public and private investments aimed to adapt to or mitigate climate change as well as the amount (and effect) of public subsidies towards low carbon investments. In this context, the capacity to respond to climate-induced threats to society and the economy and to influence global emissions is greater in larger economies than in smaller ones, all other things being equal.

***Measurement Units*:** GDP, PPP (current international $). GDP-PPP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power in the domestic currency as a U.S. dollar has in the United States.

Year(s) of coverage: 2000

Source(s): World Bank 2003 (WDI). Original Source: World Bank, International Comparison Programme database. *Note*: Estimates are based on regression performed by the World Bank.

Methodology: For analyzing GDP in the Trends feature of CAIT, dollar figures for GDP are converted from domestic currencies using 1995 official exchange rates (constant 1995 US$). This is an appropriate unit for analyzing time-series data (unlike GDP-PPP, which tends to be expressed in current, rather than constant international dollars). Source. World Bank 2003 (WDI). Original Source. World Bank national accounts data, and OECD National Accounts data files.

Table A1.4 Adaptive Capacity Index by country

Final Country List	AC Index	Final Country List	AC Index	Final Country List	AC Index	Final Country List	AC Index	Final Country List	AC Index	Final Country List	AC Index	Final Country List	AC Index	Final Country List	AC Index
American Samoa	#VALUE!	Grenada	MV	Saint Vincent/Grenadines	MV	Côte d'Ivoire	84.321	Swaziland	67.561	Armenia	55.981	Cuba	48.445	Malta	37.713
Anguilla	#VALUE!	Guadeloupe	MV	Samoa	MV	Mauritania	82.910	Cambodia	66.669	Moldova, Rep	55.944	Tunisia	48.161	Poland	37.637
Antigua and Barbuda	#VALUE!	Guam	MV	Sao Tome and Principe	MV	Sudan	81.294	Ghana	65.752	Saudi Arabia	55.620	Malaysia	48.069	China	37.534
Aruba	#VALUE!	Kiribati	MV	Serbia and Montenegro	MV	Mozambique	81.047	Guatemala	65.169	Ecuador	55.217	Jamaica	47.834	Uruguay	37.220
Barbados	#VALUE!	Korea, Dem People's Rep	MV	Seychelles	MV	Guinea	80.296	Tajikistan	64.951	El Salvador	55.109	Kuwait	47.815	Cyprus	36.781
Benin	#VALUE!	Lesotho	MV	Solomon Islands	MV	Iraq	80.002	Algeria	64.283	VietNam	54.861	Jordan	47.798	Chile	35.861
Bermuda	#VALUE!	Maldives	MV	Somalia	MV	Haiti	79.746	Morocco	63.372	Sri Lanka	54.808	Bahrain	47.345	Korea, Rep	35.287
Bhutan	#VALUE!	Marshall Islands	MV	Taiwan Province of China	MV	Zimbabwe	78.742	Gabon	63.219	Turkey	54.536	Thailand	47.040	Israel	35.260
British Virgin Islands	#VALUE!	Martinique	MV	Timor-Leste	MV	Nigeria	77.939	Syrian Arab Rep	62.031	Colombia	54.293	Mauritius	46.903	Slovenia	35.137
Cape Verde	#VALUE!	Mayotte	MV	Tokelau	MV	Senegal	77.891	Turkmenistan	61.941	Bosnia and Herzegovina	53.862	Brazil	45.925	Greece	34.243
Cayman Islands	#VALUE!	Micronesia, Fed.States of	MV	Tonga	MV	Malawi	77.317	Botswana	61.597	Belarus	53.841	Qatar	45.667	Portugal	33.467
Central African Rep	#VALUE!	Monaco	MV	Turks and Caicos Is.	MV	Zambia	77.236	Nicaragua	61.126	Ukraine	53.632	Belize	45.599	Singapore	31.021
Chad	#VALUE!	Montserrat	MV	Tuvalu	MV	Lao People's Dem Rep	77.227	Honduras	60.784	Georgia	53.523	Trinidad and Tobago	45.324	Italy	29.840
China, Hong Kong SAR	#VALUE!	Nauru	MV	US Virgin Islands	MV	Yemen	76.814	Azerbaijan	59.836	Venezuela	53.418	Croatia	44.998	Belgium	29.444
China, Macao SAR	#VALUE!	Netherlands Antilles	MV	Vanuatu	MV	Togo	76.569	Egypt	59.699	Lebanon	52.887	Panama	44.890	Ireland	28.379
Comoros	#VALUE!	New Caledonia	MV	Wallis and Futuna Is.	MV	Pakistan	76.331	Libyan Arab Jamahiriya	59.370	Dominican Rep	52.495	Bulgaria	44.574	Spain	27.025
Cook Islands	#VALUE!	Niue	MV	Afghanistan	100.000	Uganda	75.505	Uzbekistan	59.276	Macedonia, FYR	52.250	Brunei Darussalam	44.482	Austria	26.701
Djibouti	#VALUE!	Northern Mariana Is.	MV	Angola	97.787	Tanzania, United Rep	74.753	Iran, Islamic Rep	59.133	Russian Federation	52.176	Mexico	44.272	Norway	26.613
Dominica	#VALUE!	Palau	MV	Niger	97.088	Cameroon	73.762	Indonesia	58.840	Oman	51.395	Latvia	43.566	New Zealand	26.332
Equatorial Guinea	#VALUE!	Palestine, Occupied Tr.	MV	Sierra Leone	95.534	Congo	73.664	Namibia	58.752	Peru	51.277	Lithuania	42.861	France	26.140
Eritrea	#VALUE!	Pitcairn Islands	MV	Congo, Dem Rep	93.667	Nepal	73.463	Paraguay	58.041	Suriname	51.032	Bahamas	42.758	Denmark	25.777
Faeroe Islands	#VALUE!	Puerto Rico	MV	Burkina Faso	90.880	Gambia	73.350	Kyrgyzstan	58.027	Guyana	50.889	Slovakia	41.629	Iceland	25.315
Falkland Is.(Malvinas)	#VALUE!	Réunion	MV	Burundi	90.766	Kenya	72.510	Bolivia	57.459	Philippines	50.735	Argentina	41.538	Canada	24.695
French Guiana	#VALUE!	Rwanda	MV	Guinea-Bissau	87.724	Bangladesh	72.291	South Africa	57.403	Mongolia	50.025	Hungary	39.086	Finland	24.205
French Polynesia	#VALUE!	Saint Helena	MV	Liberia	87.387	Madagascar	72.107	India	56.865	Romania	49.031	Costa Rica	38.979	Sweden	24.125
French Southern Terr	#VALUE!	Saint Kitts and Nevis	MV	Ethiopia	85.373	Myanmar	71.598	Albania	56.617	United Arab Emirates	48.709	Czech Rep	38.042	Switzerland	23.986
Greenland	#VALUE!	Saint Lucia	MV	Mali	85.068	Papua New Guinea	70.794	Kazakhstan	56.391	Fiji	48.700	Estonia	38.011	Australia	23.932
														Netherlands	23.889
														United Kingdom	22.542
														Germany	22.266
														Japan	19.645
														United States	0.000