2.8 Fisheries and Aquaculture

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The importance of fish for food and nutritional security

Fish and other aquatic products provide at least 20% of protein intake for a third of the world's population, and the dependence is highest in developing countries (Béné et al. 2007). Small-scale fisheries are by far the most important for food security. They supply more than half of the protein and minerals for over 400 million people in the poorest countries of Africa and South Asia. Furthermore, fisheries and aquaculture directly employ over 36 million people worldwide, 98% of them in developing countries. They also indirectly support nearly half a billion people as dependents or in ancillary occupations (Richardson et al. 2011).

The data in Table 2.8.1 were obtained from FAOSTAT and also the standalone software FISHSTATJ. For calculating average production per year 2001–2009 the data were separated into fish and shellfish from capture fisheries and aquaculture. In terms of absolute capture production, Eastern Asia (that is, China, Korea and Japan) is the most important region at approximately 19 Mt while the developed countries of Northern Europe (such as Iceland, Norway, UK, Denmark, Ireland, Sweden and Finland), which catch approximately 6 Mt, have by far the highest per capita production at approximately 177 kg per person. When considering fish production by aquaculture, Eastern Asia (that is, China, Korea and Japan) is again the most important region producing around 38 Mt of fish and shellfish at a rate of about 23 kg per capita (see Table 2.8.1).

Standard food supply statistics for both capture and aquaculture fish and shellfish products by region and economic status are also shown in Table 2.8.1. It is clear from these data that, in general, fish comprise a fairly small component of total calories of food needed by people around the globe. If one assumes people need on average between 2500 and 3500 kcal per day, then fish is most important in Micronesia and Polynesia (140 and 97.5 kcal/person/day, respectively).

Despite the relatively small contribution by fish to the calories people need, it is an extremely important source of protein and oils in many (particularly least developed) countries/regions. To illustrate this point, data are also included in Table 2.8.1 to demonstrate the importance of fish for protein supply by region. Fish protein constitutes around 30% of the Micronesian diet and 15% of the Polynesian diet. Obviously these regional averages will tend to 'hide' specific localities within regions (and countries) where fish protein is a far more important constituent (Bell et al. 2009).

We should bear in mind that the data summarized in Table 2.8.1 are crude averages, which are often only partially informative. Mills et al. (2011), for example, concluded that inadequate reporting in official statistics of the small-scale fishing sector in developing countries probably leads to underestimates of global marine catches by about 10% and freshwater catches by about 80%. Mills et al. (2011) further point out that, even with a 10% correction, marine catches might still be underestimated, and for some freshwater fisheries underestimates are much greater than the 80% average value.

The importance, therefore, of sustaining wild capture fisheries to secure ongoing supplies of fish to poor consumers cannot be over emphasized. The fact is that the countries that depend most on fish for food rely primarily on catches from the wild. Although aquaculture continues to grow, there is no immediate prospect that it can replace these supplies. As Garcia and Rosenberg (2010) state: "The potential for sustaining catches, food output and value at or near current levels, and supporting the nutrition and livelihoods of many hundreds of millions of dependent people, will rest critically on managing fisheries more responsibly."

Biological vulnerability to climate change

It is clear that the vulnerability of aquatic food production to climate change is context-specific depending on both the temporal and spatial scales being considered. In some instances climate change will have positive effects on food security, in others negative. Nearly all food production for humans depends ultimately on primary production fuelled by the sun (photosynthesis). On 'first principles' an aquatic scientist might assume that increasing global temperatures will lead to increased vertical stratification and water column stability. Since any water column 'structure' reduces nutrient availability to the euphotic zone, primary (Behrenfeld et al. 2006, Behrenfeld and Falkowski 1997), and subsequently, secondary (Roemmich and McGowan 1995) production will fall. Reductions in global ocean primary production have indeed been noted over recent decades but some models suggest that a small increase can be expected over this century with very large regional differences

(Schmittner 2005). Changes in the dominant phytoplankton groups are certain (Reid et al. 2003, Edwards et al. 2001). Deep tropical lakes, in particular, are likely to see reduced algal abundance and declines in productivity.

In South America climate change will alter the dynamics of coastal upwelling, which sustains huge catches of anchovies, sardines and other varieties of small, pelagic fish. It has been demonstrated that changes induced by the warming effects of El Niño can cause a decline in Peruvian anchovy populations (Keefer et al. 1998).

The literature, however, also has numerous examples of increased productivity due to elevated temperatures. Some high-altitude lakes, for example, have seen increased algal abundance and productivity due to reduced ice cover, warmer water temperatures, and longer growing seasons. Similarly, increasing intensities of monsoon winds caused by higher seawater surface temperatures have led to increased nutrient supplies and upsurges in marine phyto-planktonic biomass in the Arabian Sea (Goes et al. 2005). Factors relating to ice cover can also impact aquatic productivity.

It is certain that the bio-geographic ranges of all aquatic (and terrestrial) species will be strongly impacted by rising global temperatures (Beaugrand et al. 2000, Perry et al. 2005, Beare et al. 2002). Populations at the poleward extent of their ranges will increase in abundance with warmer temperatures (Beare et al. 2002, 2004a, 2004b, 2005; Rijnsdorp et al. 2009), whereas populations in more equatorward parts of their range will decline in abundance as environments warm (Harley et al. 2006). General seasonal life cycle patterns in aquatic biota (for example, spawning, plankton blooms, growing season, and migrations) have been reviewed (Southward et al. 2004) and the changes noted have all been in the direction expected from regional changes in the climate (Edwards and Richardson 2004, Post and Stenseth 1999, Mackas et al. 1998). Differential responses between plankton components (some responding to temperature change and others to light intensity) suggest also that marine and freshwater trophodynamics are being, and can be, altered by ocean warming via simple predator-prey mismatches (Cushing 1990, Gotceitas et al. 1996, Durant et al. 2007, Hipfner 2008).

Table 2.8.1. Fisheries and aquaculture statistics by region

	Global Capture Fisheries		Global Aquaculture		Food supply from fish (both capture and aquaculture)				Protein supply from fish (both capture and aquaculture) by region		
Region	Average production per year ('000t)	Per capita production (kg)	Average production per year ('000t)	Per capita production (kg)	Apparent consumption per person (kg)	Average quantity (kg/person/year)	Calories (kcal/ person/ day)	Protein (g/ person /day)	Fish and shellfish protein (g/person/ day)	Other protein (g/person /day)	% fish protein in food supply
Year	2001/2009	2001/2009	2001/2009	2001/2009	2001/2007	2007	2007	2007	2007	2007	2007
Eastern Africa	1040	3.6	52	0.2	3.7	9.4	19.2	2.6	2.6	54.5	4.8
Middle Africa	504	4.5	1	0	9.2	15	27.9	4.1	4.1	53	7.8
Northern Africa	1682	8.9	541	2.8	9.4	8.8	17.4	2	2	86	2.3
Southern Africa	1251	22.9	6	0.1	7.6	6	11.4	1.4	1.4	68	2.1
Western Africa	2053	8.2	78	0.3	12.2	12.2	24.1	3.4	3.4	60.2	5.7
Caribbean	128	3.2	37	0.9	8.9	26.2	48.5	7.2	7.2	75.9	9.5
Central America	1824	12.6	216	1.5	9	7	13.6	1.8	1.8	71	2.5
Northern America	6070	18.1	677	2	23.5	28.3	42.3	6	6	98.7	6.1
South America	14632	39.5	1261	3.4	8.5	11.6	23.2	3	3	71.9	4.2
Central Asia	51	0.9	4	0.1	1.3	1.4	3.6	0	0	80.2	0
Eastern Asia	19279	12.7	38765	25.5	29.2	29.8	61.8	8.6	8.6	79.4	10.8
South-Eastern Asia	15102	27.2	7722	13.8	26.5	26.4	49.1	7.5	7.5	64.5	11.6
Southern Asia	6116	3.8	3947	2.5	5.5	32.1	67.4	9.9	9.9	68.1	14.5
Western Asia	1123	5.3	175	0.8	6	8.6	15.9	2	2	85	2.4
Eastern Europe	3817	12.8	223	0.8	13.7	10.8	24.8	3	3	88.7	3.4
Northern Europe	6369	177.6	825	22.9	30.5	34.1	72	10.1	10.1	107.9	9.4
Southern Europe	1548	10.8	582	4.1	29.5	20.8	39	5.6	5.6	97.2	5.8
Western Europe	1368	7.4	355	1.9	21.9	20.7	44.4	5.3	5.3	104.7	5
Australia and New Zealand	728	29.9	146	5.9	24.2	25	40	6	6	101.5	5.9
Melanesia	399	50.2	2	0.3	7.3	28.8	62	8.2	8.2	69.8	11.8
Micronesia	80	149	4	8.5	12.8	74	140	21	21	73	28.8
Polynesia	39	60.3	2	3.1	32.7	46.5	97.5	13	13	89	14.6

Source: FAOSTAT

Coral reefs are among the world's most biologically diverse ecosystems but are especially vulnerable to three aspects of climate change: (1) ocean-acidification, (2) rising temperatures and (3) rising sea-water levels. From the aspect of food security, coral reefs are extremely important since they support important fisheries close to many human communities particularly dependent on coral reef fish for food (Jones et al. 2004). Increased levels of CO_2 in the atmosphere have already caused large falls in ocean pH (increased acidity) which can affect shell and/or skeleton growth in corals (Hughes et al. 2003) but also many others (Kleypas et al. 1999, Zondervan et al. 2001). The potential ability of fish (and marine biota in general) to adapt to increasing levels of ocean acidity (Le Quesne and Pinnegar 2011) is not known but many cope continually with large, natural (seasonal) fluctuations in pH (Provoost et al. 2010). The fact that coral reefs, however, may be particularly vulnerable to ocean acidity is a serious concern for food security due the relative importance of reef fisheries in the most vulnerable countries. Corals are also susceptible to abrupt increases in water temperatures, which cause their symbiotic algae to leave, resulting in the phenomenon of coral bleaching. When bleached corals do not recover, algae can grow over them transforming the ecosystem. Bleaching usually occurs when temperatures exceed a threshold of about 0.8 to 1 °C above mean summer maximum levels for at least four weeks (Hoegh-Guldberg et al. 2007, Hughes et al. 2003). Many reef-building corals live very close to their upper thermal tolerances and are thus extremely vulnerable to warming (Hughes et al. 2003). Numerous cases of coral bleaching due to recent warming have been reported (Hoegh-Guldberg 1999, Hoegh-Guldberg et al. 2007, Sheppard et al. 2003). As mentioned above for fish, one of the most obvious expected consequences of rising temperatures will be a poleward shift in species distributions. Many corals, however, are not expected to be able to keep pace with predicted rates of sea level rise (Knowlton 2001).

Furthermore aquatic biota may be vulnerable to changes in other aquatic chemical properties including dissolved oxygen and other inorganic nutrients. It is known that the oxygen concentrations in the 'ventilated thermocline' have been decreasing in most ocean basins since 1970 (Emerson et al. 2004) although it is not clear what impact such changes will have on marine productivity and fisheries.

On a global scale, it has also been noted that outbreaks of disease have increased over the last three decades in many marine groups including corals, echinoderms, mammals, molluscs and turtles (Ward and Lafferty 2004). Causes remain uncertain, although temperature is one factor that has been implicated. Previously unseen diseases have also emerged in new areas through shifts in distribution of hosts or pathogens, many of which are in response to climate change (Harvell et al. 1999).

As far as impacts of climate change on aquaculture are concerned the Third Assessment Report of the IPCC (IPCC 2001) identified the following potential negative impacts:

1. Stress due to increased temperature and oxygen demands;
2. Uncertain supplies of freshwater;
3. Extreme weather events;
4. Sea level rise;
5. Increased frequency of diseases and toxic events and;
6. Uncertain supplies of fishmeal from capture fisheries.

There may also be additional problems with non-native species invasions, declining oxygen concentrations, and possibly increased blooms of harmful algae (Parry et al. 2007), although these latter are also strongly influenced by non-climate related factors. Local conditions in rearing areas may become unsuitable for many traditional species, which may then need to be moved poleward (Stenevik and Sundby 2007) or to cooler offshore water, or replaced with other species.

Possible positive impacts of climate change on aquaculture include increased food conversion efficiencies and growth rates in warmer waters, increased length of the growing season, and range expansions poleward due to decreases in ice (Parry et al. 2007). If primary production increased in aquaculture areas, it could provide more food for filter-feeding invertebrates (Parry et al. 2007). De Silva and Soto (2009) provide a review of potential impacts of climate change on aquaculture. They note that 50 to 70% of aquaculture occurs between the Tropics of Cancer and Capricorn, particularly in Asia. The highest production is by finfish in freshwater, while the culture of crustaceans is greatest in brackish waters, while that of molluscs is mainly marine. De Silva and Soto (2009) concluded that the impacts of climate change are context specific and difficult to predict. Salinity changes may be particularly important in brackish waters (mainly crustaceans) due to changes in runoff, marine circulation, etc. In temperate regions increases in harmful parasites and other pathogens might occur (for example, Handisyde et al. 2006).

There is limited observational information on climate change impacts on all aquatic (especially marine) ecosystems, compared to what is available on land. For example, only 0.1% of the time series examined in the IPCC reports were marine (Richardson and Poloczanska 2008). Many uncertainties and research gaps remain, in particular the effects of synergistic and cumulative interactions among stressors (such as rising temperatures, fishing and pollution combined), the occurrences and roles of critical thresholds, and the abilities of marine and aquatic organisms to adapt and evolve to the changes (Berteaux et al. 2004, Skelly and Freidenburg 2012).

Socioeconomic vulnerability to climate change

Human activities are especially vulnerable to the direct threats caused by rises in sea level which may completely wipe out some island communities in the next few decades (Pelling and Uitto 2001, Titus and Richman 2001, Lewis 1990). Global average sea level has been rising at an average rate of 1.8 mm per year since 1961 (Douglas 2001, Miller and Douglas 2004, Church et al. 2004), and the rate has accelerated since 1993 to about 3.1 mm per year due to waning mountain glaciers and snow cover, and losses from the ice sheets of Greenland and Antarctica (Bindoff et al. 2007). Specific socio-economic vulnerabilities to climate change and sea level rise exist where the stresses on natural low-lying coastal systems coincide with low human adaptive capacity and/or high exposure and include: deltas, especially Asian megadeltas (such as the Ganges- Brahmaputra in Bangladesh and West Bengal); low-lying coastal urban areas, especially areas prone to natural or human-induced subsidence and tropical storm landfall (such as New Orleans, Shanghai); small islands, especially low-lying atolls, such as the Maldives (Nicholls and Cazenave 2010, Nicholls et al. 2011). Little attention has been paid to the connections between land use and inland fish capture production, such as dry season trade-offs between rice and inland fish production on the floodplains of Bangladesh.

The world's fisheries provide more than 2.6 billion people with at least 20% of their average annual per capita protein intake, according to the United Nation's Food and Agriculture Organization (FAO). Localized studies on the importance of fish for food security have been published. Bell et al. (2009), for example, highlighted the relatively high importance of fisheries to feeding populations in Pacific Island states, while Allison et al. (2007) focused on sub-Saharan Africa. The only globally comprehensive study examining the vulnerability of fishing communities (Allison et al. 2009) suggests that millions of people will face unprecedented hardship in the future. One hundred and thirty two national economies were examined for vulnerability to climate change using environmental, fisheries, dietary and economic factors. Countries most at risk were not necessarily those that will experience the greatest direct environmental impacts on their fisheries. Instead, they are countries where fish are crucial for diet, income and trade yet there is a lack of capacity to adapt to problems caused by climate change (such as loss of coral reef habitats to the bleaching effects of warmer waters). The fisheries in four countries in Africa (Malawi, Guinea, Senegal and Uganda), four Asian (Bangladesh, Cambodia, Pakistan and Yemen), and two from South America (Peru and Colombia) were identified as the most economically vulnerable. Of the 33 countries that were considered highly vulnerable, 19 had already been classified by the United Nations as 'least developed' due to their particularly poor socioeconomic conditions. It was noted that these 'highly vulnerable' countries also produce 20% of the world's fish exports (by value), and these countries should be prioritized for adaptation efforts that will allow them to endure the effects of climate change and maintain or enhance the contribution that fisheries can make to poverty reduction. It is also worth noting that marine fisheries production by northern countries will see most direct climate change impact, but economically those in the tropics and subtropics will suffer most, because fish are so important in their diets and because they have limited capacity to develop other sources of income and food. Uganda, for example, though landlocked, depends greatly on freshwater fish, making it highly vulnerable to climate change impacts. One of the shortcomings of Allison's study is that data on such variables as the social and economic impacts of fisheries at country levels were often lacking and this was particularly evident for subsistence fishing in the Pacific Ocean.

In conclusion it is difficult to improve on the following summary by Cochrane et al. (2009):

"Although resource-dependent communities have adapted to change throughout history, projected climate change poses multiple additional risks to fishery dependent communities that might limit the effectiveness of past adaptive strategies. The FAO Technical Workshop in Rome (2009) concluded that adaptation strategies will require to be context and location specific and to consider impacts both short-term (e.g. increased frequency of severe events) and long-term (e.g. reduced productivity of aquatic ecosystems). All three levels of adaptation (community, national and regional) will clearly require and benefit from stronger capacity building, through raising awareness on climate change impacts on fisheries and aquaculture, promotion of general education and targeted initiatives in and outside the sector. Options to increase resilience and adaptability through improved fisheries and aquaculture management include the adoption as standard practice of adaptive and precautionary management. The ecosystem approaches to fisheries (EAF) and to aquaculture (EAA) should be adopted to increase the resilience of aquatic resources ecosystems, fisheries and aquaculture production systems, and aquatic resource dependent communities. Aquaculture systems, which are less or non-reliant on fishmeal and fish oil inputs (e.g. bivalves and macroalgae), have better scope for expansion than production systems dependent on capture fisheries commodities. Adaptation options also encompass diversification of livelihoods and promotion of aquaculture crop insurance in the face of potentially reduced or more variable yields. In the face of more frequent severe weather events, strategies for reducing vulnerabilities of fishing and fish farming communities have to address measures including: investment and capacity building on improved forecasting; early warning systems; safer harbours and landings; and safety at sea. More generally, adaptation strategies should promote disaster risk management, including disaster preparedness, and integrated coastal area management. National climate change adaptation and food security policies and programmes would need to fully integrate the fisheries and aquaculture sector (and, if non-existent, should be drafted and enacted immediately). This will help ensure that potential climate change impacts will be integrated into broader national development (including infrastructure) planning. Adaptations by other sectors will have impacts on fisheries, in particular inland fisheries and aquaculture (e.g. irrigation infrastructure, dams, fertilizer use runoff), and will require carefully considered trade-offs or compromises. Interactions between food production systems could compound the effects of climate change on fisheries production systems but also offer opportunities. Aquaculture based livelihoods could for example be promoted in the case of salination of deltaic areas leading to loss of agricultural land."

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