CLIMATE CHANGE FOR FISHERIES AND AQUACULTURE

TECHNICAL BACKGROUND DOCUMENT

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THE IMPORTANCE OF FISHERIES AND AQUACULTURE TO LIVELIHOODS AND FOOD SECURITY

Fisheries and aquaculture play an important but often unsung role in economies around the world, in both developed and developing countries. Easily overlooked and often underreported, the following points provide a glimpse of the macroeconomic and microeconomic importance of the sector.

Production and trade of aquatic product

- Aquatic products are among the most widely traded foods. About 40 percent of global production enters international trade.
- Fishery trade is particularly important as a source of foreign currency for developing countries. At present, their net earnings from aquatic products are greater than the combined earnings from the major agricultural commodities of rice, coffee, bananas, rubber, sugar and tea.
- Capture fisheries production in 2006 was 92 million tonnes, which represented a small decline from 2005. Though the net quantity for human consumption may rise, production is not expected to increase much further, as most stocks are reaching or sometimes exceeding capacity limits.
- Aquaculture production was 51.7 million tonnes in 2006. It continues to grow more rapidly than all other animal food producing sectors, with a average global growth rate of 8.8 percent per year since 1970, compared to 2.8 percent for terrestrial farmed meat production systems.
- If growth in aquaculture can be sustained, it is likely to fulfil the increasing demand for aquatic food supplies by supplying more than 50 percent of the total aquatic food consumption by 2015.

Contribution to GDP and livelihood

- The fisheries and aquaculture sector contribution to Gross Domestic Product (GDP) typically ranges from around 0.5 to 2.5 percent, but may exceed 7 percent in some countries, which often compares very significantly with agricultural sector GDP.
- Millions of people around the world depend on fisheries and aquaculture, directly or indirectly, for their livelihoods. Currently, an estimated 42 million people work full or part time as fishers and fish farmers, with the great majority in developing countries, principally in Asia. Hundreds of millions of other people work in the sector as occasional fishers or in associated activities including supply and post-harvest services, marketing and distribution.
- Growth in sector employment, largely outpacing that of agriculture, has been mainly in small-scale fisheries and in the aquaculture sector in the developing world where it has important seasonal income, food supply and security impacts.

Fishery products and food security

- Fish[1] is highly nutritious, rich in micronutrients, minerals, essential fatty acids and proteins. It represents a valuable supplement to diets that otherwise lack essential vitamins and minerals, providing nutrients that have particular importance in natal and child health and development.
- Fish products provide more than 2.8 billion people (2.6 billion of whom are from developing countries) with about 20 percent of their average per capita intake of animal protein.
- Fish contributes to, or exceeds, 50 percent of total animal protein intake in some small island and other developing states.

[1] "Fish" refers to all aquatic food products including all invertebrate groups (e.g. crustaceans, molluscs)

The responsible management of the resources and ecosystems upon which this important sector depends is a major challenge for world food security. At the same time, the sector is threatened by external factors such as pollution runoff, land-use transformation and competing aquatic resource uses upon which the impacts of climate changes could have an important compounding effect. The many people dependent on fisheries and aquaculture – as producers, consumers or intermediaries in inland or coastal areas – will be particularly vulnerable to the direct and indirect impacts of predicted climatic changes, whether through changes in physical environments, ecosystems or aquatic stocks, or through impacts on infrastructure, fishing or farming operations, or livelihood options.

This summary document reviews: the predicted impacts of climate change on physical and ecological features of aquatic systems and their impacts on the fisheries and aquaculture sector; the role of the sector in climate change mitigation; and the opportunities and threats to people and communities dependent on the sector as determined by their vulnerability and potential for adaptation.

Why separate out climate change implications for fisheries and aquaculture from other food production systems?

Wild capture fisheries are fundamentally different from other food production systems in their linkages and responses to climate change and in the food security outcomes. Aquaculture also has strong links to capture fisheries (e.g. for inputs), and both feed into distinct and specialized post-harvest and market chains. Conclusions on food supply and security based on terrestrial contexts usually cannot be applied directly to the sector, indicating that special consideration is needed to ensure policy and management responses are effective.

For example, most fishing depends on wild populations whose variability depends on environmental processes governing the supply of young stock, and feeding and predation conditions through the life cycle. Open water populations cannot be enhanced by simply adding fertilizers as in agriculture, nor can effects of environmental change be quickly observed. Many fish populations migrate over long distances, passing through multiple territorial waters. This creates issues of transboundary management, control and utilization, driven by natural environmental factors. Climate change impacts could change resource access “winners” and “losers”, at both community and national level.

Unlike most terrestrial animals, all aquatic animal species for human consumption are poikilothermic, meaning their body temperatures vary with the ambient temperature. Any changes in habitat temperatures will significantly influence metabolism and, hence, growth rate, total production, reproduction seasonality and possibly reproductive efficacy, and susceptibility to diseases and toxins. Climate change-induced temperature variations will therefore have a much stronger impact on the spatial distribution of fishing and aquaculture activities and on their productivity and yields.

Much fishing is still an open access activity and non-boat-based fisheries, such as collecting clams on a beach, using handlines or simple bamboo traps in rice fields, require little capitalization. Fishing, therefore, often function as a last-resort activity, or serves to supplement food supply when other sources are weak – playing an important role in adaptive strategies. However, there are potential mismatches between these important social objectives and the fisheries management concerns of over-exploitation of resources and the need to limit access or restrict fishing to particular species, places or times.

Climate change is only one among many environmental and anthropogenic stresses faced by fisheries and aquaculture but is likely to exacerbate the difficulties of achieving sustainable practices. However, the magnitude and direction of climate change-specific stressors will vary from one aquatic system to another, or may play only a small role when compared to other stressors. Climate change may also offer win-win outcomes where adaptation or mitigation measures improve economic efficiency and resilience to climatic and other change vectors. For example, this could include decreasing fishing effort to sustainable levels, decreasing fuel use and hence CO_2 emissions, or reducing aquaculture dependence on fishmeal or oils.

PHYSICAL AND ECOLOGICAL IMPACTS OF CLIMATE CHANGE ON MARINE AND INLAND ECOSYSTEMS AND FISHERY RESOURCES

This section summarizes the potential physical and ecological impacts of climate change on aquatic systems. As more information develops, more detailed documentation of regional and local climatic impacts will assist further in determining ecological, supply or food security hotspots.

Changes in physical environments

Marine waters

Higher frequency and intensity climate processes, such as El Niño-Southern Oscillation (ENSO), and decadal-scale regime shifts, are expect to continue, with possible increases in their intensity or/and frequency in coming decades. The oceans are warming, but with geographical differences and some decadal variability. Warming is more intense in surface waters but is not exclusive to these, with the Atlantic showing particularly clear signs of deep warming.

Changes in ocean salinity have been observed, with near-surface waters in the more evaporative regions increasing in salinity in almost all ocean basins, and high latitudes showing decreasing salinity due to greater precipitation, higher runoff, melting ice and advection. The oceans are also becoming more acidic, with likely negative consequences to many coral reef and calcium-bearing organisms. Although there are no clearly discernable net changes in ocean upwelling patterns, there are indications that their seasonality may be affected.

Global average sea level has been rising since 1961, but the rate has been accelerated since 1993. Although not geographically uniform, large coastal land losses are likely on the Atlantic and Gulf of Mexico coasts of the Americas, the Mediterranean, the Baltic and small-island regions, while in other areas, such as Asia, large and heavily populated deltaic regions may also be strongly impacted

Inland waters

There has been no global assessment of warming of inland waters but many lakes have shown moderate to strong warming since the 1960s. There are particular concerns for African lakes, as the atmospheric temperature of the continent is predicted to be higher than the global average and rainfall is projected to decrease. Likewise, wetlands and shallow rivers are susceptible to changes in temperature and precipitation and water levels may drop to the point of completely drying out more completely in dry seasons. Increased temperature may lead to stronger, earlier and longer stratification of lakes and reservoirs and, with limited or no seasonal turnover, greater deoxygenation (i.e. Hypoxia) of bottom layers.

River runoff is expected to increase at higher latitudes but decrease in parts of West Africa, southern Europe and southern Latin America. Overall, a global temperature increase of 1°C is associated with a four percent increase in river run-off. Changes in flood areas, timing and duration are also expected.

Changes in biological functions and fish stocks

Marine waters

Although large regional differences exist, especially at regional scales, most models predict a slight decrease in primary production in the seas and oceans and many models predict composition shifts to smaller phytoplankton which are likely to lead to changes in food webs in general. Changes in fish distributions in response to climate variations have been observed, generally consisting of poleward expansions of warmer-water species and poleward contractions of colder-water species. Changes are likely to affect pelagic species more rapidly than other species groups.

Inland waters

In general, temperature changes are likely to impact cold-water species negatively, warm-water species positively, and cool-water species positively in their northern ranges and negatively in their southern ranges. Also, there will likely be a general shift of cool- and warm-water species northward in northern hemisphere rivers. The abundance and species diversity of riverine fishes are predicted to be particularly sensitive to climatic disturbances, since lower dry season water levels may reduce the number of individuals able to spawn successfully. The timing of flood events is a critical physiological trigger that induces fish to migrate and spawn at the onset of the flood which enables their eggs and larvae to be transported to nursery areas on flood plains.

Ecological forecasts

A range of impacts on aquatic ecosystems can be predicted in association with large-scale changes in temperature, precipitation, winds and acidification. It is very likely that over the short term (within a few years), there will be negative impacts on the physiology of fish in localities where temperatures increase, through limiting oxygen transport. This would have significant impacts on aquaculture and result in changes in distribution, and probably abundance, of both freshwater and marine species. There is high confidence in predictions that over the medium term (a few years to a decade), temperature-regulated physiological stresses and changes in the timing of life cycles will impact the recruitment success and therefore the abundance of many marine and inland aquatic populations and species composition of marine and inland communities. There is lower confidence in long-term (multi-decadal) time-scale predictions. Predicted impacts depend upon, among other factors, changes in net primary production in the oceans and its transfer to higher trophic levels.

CLIMATE CHANGE IMPACTS ON FISHERIES, AQUACULTURE AND THEIR COMMUNITIES

Overall impacts on fisheries, aquaculture and fishery-dependent communities

Fisheries

The impacts of physical and biological changes on fisheries communities[2] will be as varied as the changes themselves. Both negative and positive impacts could be foreseen, their strength depending on the vulnerability of each community, the combination of potential impacts (sensitivity and exposure) and adaptive capacity. Impacts would be felt through changes in capture, production and marketing costs, changes in sales prices, and possible increases in risks of damage or loss of infrastructure, fishing tools and housing. Fishery-dependent communities may also face increased vulnerability in terms of less stable livelihoods, decreases in availability or quality of fish for food,

[2] "Communities", defined in the widest sense possible, ranging from local fishing communities to large-scale fishing production systems, from suppliers to consumers, and from those that manage to those that are managed.

and safety risks due to fishing in harsher weather conditions and further from their landing sites. Within communities and households, existing gender issues related to differentiated access to resources and occupational change in markets, distribution and processing, where women currently play a significant role, may be heightened under conditions of stress and increased competition for resources and jobs stemming from climate change.

Aquaculture
Impacts on aquaculture could be positive or negative, arising from direct and indirect impacts on the natural resources aquaculture requires, namely water, land, seed, feed and energy. As fisheries provide significant feed and seed inputs, the impacts of climate change on them will also, in turn, affect the productivity and profitability of aquaculture systems. Vulnerability of aquaculture-based communities will stem from their resource dependency and exposure to extreme weather events.

Climatic changes could increase physiological stress on cultured stock. This would not only affect productivity but also increase vulnerability to diseases and, in turn, impose higher risks and reduce returns to farmers. Interactions of fisheries and aquaculture subsectors could create other impacts. For example, extreme weather events could result in escapes of farmed stock and contribute to reductions in genetic diversity of the wild stock, affecting biodiversity more widely.

These impacts will be combined with other aspects affecting adaptive capabilities, such as the increased pressure that ever larger coastal[3] populations place on resources; any political, institutional and management rigidity that negatively impacts on communities' adaptive strategies; deficiencies in monitoring and early-warning systems or in emergency and risk planning; as well as other non-climate factors such as poverty, inequality, food insecurity, conflict and disease.

However, new opportunities and positive impacts emerging from such areas as changes in species and new markets also could be part of future changes. So far, these opportunities are not well understood but, nevertheless, are possible. A community's ability to benefit also will depend on its adaptive capacity.

<u>Specific impacts to food security</u>

Climate change impacts in the sector will potentially act across the four dimensions of food security: availability, stability, access and utilization.

Availability of aquatic products will vary through changes in ecosystems, production, species distribution and habitats. Changes will occur at regional and local levels in freshwater and marine systems due to ecosystem shifts and changing aquaculture options, which depend on availability of key inputs. Production from aquatic resources, whether through fisheries or aquaculture may be impacted by the adaptive capacity of management measures controlling temporal and spatial access.

Stability of supply will be impacted by changes in seasonality, increased variance of ecosystem productivity, increased supply risks and reduced supply predictability – issues that may also have large impacts on supply chain costs and their flexibility to respond to variation.

Access to fish for food will be affected by changes distribution of fish species and in livelihoods combined with impacts transferred from other sectors such as increases in prices of substitute food products; competition for supply; and information asymmetries. Policies and measures tackling

[3] "Coastal" in this sense refers to lacustrine, riparian and marine coasts.

climate change impacts may indirectly hamper people's access to food by constraining individuals' expressions of their entitlements and rights to food.

Utilization of the nutrients and the nutritional value of fishery products will be affected by changing supply quality and market chain disruptions. In some cases, an adjustment period will be required to move to species that are not traditionally consumed. These issues are most critical for countries with a high per capita consumption of aquatic proteins.

Availability of fish for food can be improved by making better use of production. This means reducing post-harvest losses and increasing the percentage of use for direct human consumption. Losses caused by spoilage amount to about 10 to 12 million tonnes per year and an estimated 20 million tonnes of fish a year are discarded at sea. Climate change will add to the complexity of addressing these issues and climate events may have a direct negative impact on the control of spoilage and waste.

Vulnerability hot spots

The extent to which people and systems are affected by climate change (their vulnerability) is determined by three factors: their exposure to specific change, their sensitivity to that change, and their ability to respond to impacts or take advantage of opportunities. The non-linear interactions of these factors mean that vulnerability is unevenly distributed, sometimes in surprising ways. It is important to understand patterns of vulnerability to specify and prioritize adaptation interventions.

Fisheries located in the high latitudes and those that rely on climate change-susceptible systems, such as upwelling or coral reef systems, appear to have most potential exposure to impacts. However, low adaptive capacities are important – as they elevate the vulnerability of least-developed countries even though greater warming is predicted to be greater at higher latitudes. Communities located in deltas, coral atolls and ice dominated coasts will also be particularly vulnerable to sea level rise and associated risks of flooding, saline intrusion and coastal erosion. Coastal communities and small island states without proper extreme weather adaptation programmes, in terms of infrastructure design, early warning systems and knowledge of appropriate behaviour, will also be at high risk.

For aquaculture, Asia is by far the major contributor and at present the most vulnerable region. However, recognizing the high growth potential for aquaculture in Africa, Latin America and other regions, potential climate impacts need to be considered in relation to future developments. In deltaic areas in Asia, agriculture is a predominant means of livelihood and contributes significantly to food security. The loss of agriculture productivity, due to salination from sea level rise and seawater intrusion, could have an important impact and lead to aquaculture taking a major climate change adaptive role as an alternative livelihood, compensating for income and some aspects of food supply.

Transboundary issues

The potential spatial displacement of aquatic resources and people associated with climate change impacts, and the greater variability characteristics of transboundary resources would require existing bilateral and regional structures and processes to be strengthened or given more focus. Policy and legal issues will need to be developed. Regional market and trading mechanisms also would be more important in linking and buffering supply variability and maintaining sectoral value and investment.

Current examples of impacts from displacing populations due to climatic variations include, for example, the on-going negotiations between the United States and Canada over access to Pacific salmon, Pacific sardine and Pacific Ocean skipjack tuna resources, whose spatial distributions are largely determined by environmental variability. The potential increase and expansion of aquatic diseases in aquaculture and the expansion of exotic pest species will require specific transboundary actions, particularly in large international watersheds such as the Mekong River and the Mediterranean.

Climate change impacts on fisheries and aquaculture from other sectors

Indirect impacts arising from adaptation by other sectors and from climate change mitigation activities, such as use of alternative energy sources, could be significant and may even overshadow the direct impacts of climate change. An ecosystem approach would be required, and system-wide evaluation and planning of mitigation and adaptation strategies will need to include downstream impacts on other sectors.

Mitigation strategies in other sectors

Offshore wind, wave and tidal energy devices are being developed increasingly for renewable energy, but could have negative impacts. Greater nuclear power capacity is also being proposed, usually with coastal or inland water cooling, and the discharge of heated waters. Construction and operation of all of these systems could affect aquatic resources directly (including spawning, overwintering, nursery and feeding grounds, and migratory pathways). In shallow coastal waters, their structural obstruction and undersea transmission cables could also interfere with fishing. However, suitable siting and construction can give shelter for aquaculture, protection from illegal fishing, opportunities for habitat and stock enhancement and, with heated water, opportunities for enhancing growth and species choice.

New investments in hydropower are also being considered, often in combination with water supply regulation. However, dams may interrupt connectivity between habitats, preventing fish from completing their life cycles, and impact water flows that are important for habitat maintenance and serve as physiological triggers for migration. Flood sizes and duration, which determine size and timing of feeding areas in floodplains, could also be impacted, and reduced flows can have important effects on salinity in, and dissolved nutrient supply to, coastal ecosystems.

Increased interest in production of biofuels will have a compound impact on crop prices, including impacts on price and availability of feeds for aquaculture. At this stage, aquatic based biofuels, such as those based on algal sugars, are only experimental but may lead to negative impacts of resource competition or positive impacts of integration opportunities with various aquaculture systems.

Adaptation strategies in other sectors

Changes in precipitation patterns and water table conditions, and increasing frequency of extreme flooding in lake and river basins may promote agriculture sector demand for more flood control, drainage and irrigation schemes. These could exacerbate negative impacts of climate change on fisheries and aquaculture. Flood control embankments or levees may constrain river flows and increase peak and mean discharge rates and flooding events elsewhere. Increased erosion of river beds can reduce fish populations that spawn there. Increased sediment loads can choke spawning substrates, affect reproductive success and block migration routes. Flood control efforts also may reduce the depth and surface area of dry season water bodies and, hence, their carrying capacity for critical stocks.

Though some irrigation demand could be met by using reservoirs or abstracting water from surface and ground waters, dry season water is often abstracted from residual pools and water bodies remaining after flood-waters have receded. These provide critical dry season refuge habitat for many floodplain species and, beyond certain thresholds, their production is highly sensitive to water removal. Changing locations of watering points for livestock and adaptive strategies to deal with heat stress may place further strain on dry season fish habitats. Increasing intensity of fertilizer and pesticide application to mitigate impacts of climate change on agriculture could also adversely affect water quality in rivers, lakes and coastal zones and, thereby, impact fisheries. These water quality changes may be further exacerbated by the impacts of greater waste concentrations from human settlements, from reduced per capita water use, and from greater risk of disruption of waste treatment processes. Increased agricultural water demand may also constrain aquaculture, by reducing water availability or by requiring aquaculture to use irrigation drainage water which will further reduce water quality.

Soil erosion from changing land use also could cause impact by increasing sediment loads. Greater downstream sediment transport may adversely impact coral reef and other coastal fisheries by affecting light penetration and physiological processes, or interfere with feeding in coastal aquaculture. Yet, increasing sediment also may help sustain river deltas and critical habitats such as mangroves that are threatened by rising sea levels and increased storm erosion. In addition, changes in estuarine salinity distribution brought about by changes to river discharge rates may be important.

Cumulative effects of human activity and climate change on ecosystem productivity

The resilience of many ecosystems is likely to be exceeded by an unprecedented combination of climate change and other global change drivers. Climate change, pollution, fragmentation and loss of habitat (e.g. destructive fishing activities, coastal zone development), invasive species infestations and over-harvesting from fisheries may individually or together result in severe impacts on the production of the world's aquatic systems and the services they provide. The impacts on aquatic life from these stressors may be exacerbated by climatic changes and the ability of ecosystems to cope (resilience) or recover will be impaired. Therefore, the combined effects of these may steadily and, in some cases, possibly sharply increase the vulnerability of the world's aquatic resources, with important ecological, economic and social implications. In this respect, too, the role of fishery sector stakeholders in contributing to the long-term health of the resource, not just for food supply and security, but for the continued provision of wider ecosystem services, will become much more important.

CLIMATE CHANGE ADAPTATION IN FISHERIES AND AQUACULTURE

Adaptation strategies are location and context specific and, hence, difficult to model and predict. This section presents some existing and potential strategies for the sector that could reduce vulnerability and increase adaptive capacities towards climate changes and changes which may combine with them.

Potential adaptation measures in fisheries

A wide range of adaptations is possible, either carried out in anticipation of future effects or in response to impacts once they have occurred. As shown below, some are implemented by public institutions, others by private individuals. In general, responses to direct impacts of extreme events on fisheries infrastructure and communities are likely to be more effective if they are anticipatory, as part of long-term integrated management planning. However, preparation should be commensurate with risk, as excessive protective measures could themselves have negative social and economic impacts.

Table 1. Examples of potential adaptation measures in fisheries

Impact of climate change on fisheries	Potential adaptation measures	Responsibility	Reactive/ Anticipatory
Reduced yield	Access higher value markets/shifting targeted species	Public/private	Either
	Increase effort or fishing power*	Private	Either
	Reduce costs to increase efficiency	Private	Either
	Diversify livelihoods	Private	Either
	Exit the fishery	Private	Either
Increased variability of yield	Diversify livelihood portfolio	Private	Either
	Design insurance schemes	Public	Anticipatory
Change in distribution of fisheries	Migration of fishing effort/strategies and processing/distribution facilities	Private/public	Either
Reduced profitability	Exit the fishery	Private	Either
Vulnerability of infrastructure and communities to flooding, sea level and surges	Add new or improved physical defences	Private/public	Anticipatory
	Managed retreat/accommodation	Private/public	Either
	Rehabilitate infrastructure, design disaster response	Private/public	Reactive
	Integrate coastal management	Public	Anticipatory
	Set up early warning systems, education	Public/private	Anticipatory
Increased dangers of fishing	Set up weather warning system	Public	Anticipatory
	Invest in improved vessel stability/safety/communications	Private	Anticipatory
Influx of new fishers	Support existing local management institutions, diversify livelihoods.	Public	Either

* May risk exacerbating overexploitation.

As climatic change increases environmental variation, fisheries managers who have not already done so will have to move beyond static understandings of managed stocks or populations. Inflexible management approaches may no longer apply. There is a need for implementation of adaptive holistic, integrated and participatory approaches to fisheries management, as required for an ecosystem approach.

Potential adaptation measures in aquaculture

In most cases and for most climate change-related impacts, improved management and better aquaculture practices would be the best and most immediate form of adaptation, providing a sound basis for production that could accommodate possible impacts. An ecosystem approach to aquaculture (EAA) management would be a most effective thematic adaptation measure. As with capture fisheries, responses range from public to private sector and can be reactive or anticipatory.

The aquaculture of extractive species – using nutrients and carbon directly from the environment such as bivalves and macroalgae – may deserve further attention for its positive ecosystem characteristics and potential food security benefits. Integrating aquaculture with other practices, including agro-aquaculture, multitrophic aquaculture and culture-based fisheries, also offers the possibility of recycling nutrients and using energy and water much more efficiently. These could include fisheries and assist coastal communities in general. Short-cycle aquaculture may also be valuable, using new species or strains and new technologies or management practices to fit into seasonal opportunities. Aquaculture could be a useful adaptation option for other sectors, such as coastal agriculture under salinization threats, and could also have a role in biofuel production, through use of algal biomass or discards and by-products of fish processing.

For feed-based aquaculture, dependence of capture fisheries on fish meal and oil, and growing competition for terrestrial raw materials is most important. Feeding materials and formulation strategies will be particularly important in maintaining and expanding output while containing costs and energy inputs, and improving resilience to climate change. Adaptations include changing to less carnivorous species, genetic improvements, feed source diversification, better formulation, quality control and management

The Table below summarizes most relevant specific adaptation measures for aquaculture.

Table 2. Climate change-related impacts and potential adaptation measures in aquaculture

Climatic change element	**Impacts on aquaculture or related function**	**Adaptive measures**
Warming	Raise above optimal range of tolerance of farmed species	Use better feeds, more care in handling, selective breeding and genetic improvements for higher temperature tolerance (and other related conditions)
	Increase in growth; higher production	Increase feed input; adjust harvest and market schedules
	Increase in eutrophication and upwelling; mortality of farmed stock	Improve planning and siting to conform to CC predictions; establish regular monitoring and emergency procedures
	Increase virulence of dormant pathogens and expansion of new diseases	Focus management to reduce stress; set up biosecurity measures; monitor to reduce health risks; improve treatments, management strategies; make genetic improvements for higher resistance
	Limitations on fish meal and fish oil supplies/ price	Identify fish meal and fish oil replacement; develop new forms of feed management, make genetic improvement for alternative feeds; shift to non-carnivorous species; culture bivalves and seaweeds wherever possible
Sea level rise and other circulation changes	Intrusion of salt water	Shift stenohaline species upstream; introduce marine or euryhaline species in old facilities
	Loss of agricultural land	Provide alternative livelihoods through aquaculture, building capacity and infrastructure
	Reduced catches from coastal fisheries, seedstock	Make greater use of hatchery seed; protect nursery habitats; develop/use formulated pellet

	disruptions, reduced options for aquaculture feeds; income loss to fishers	feeds (higher cost but less environmentally degrading); develop alternative livelihoods for suppliers
	Increase of harmful algal blooms (HABs)	Improve monitoring and early warning systems; change water abstraction points where feasible
Acidification	Impact on calcareous shell formation/deposition	Adapt production and handling techniques; move production zones
Water stress and drought conditions	Limitations for freshwater abstraction	Improve efficacy of water usage; encourage non-consumptive water use in aquaculture, e.g. culture based fisheries; encourage development of mariculture where possible
	Change in water-retention period (inland systems reduced, coastal lagoons increased)	Use different/faster growing fish species; increase efficacy of water sharing with primary users, e.g. irrigation of rice paddy; change species in lagoons
	Reduced availability and period change of wild seed stocks	Shift to artificially propagated seed (extra cost); improve seed quality and production efficiency; close the life cycle of more farmed species
Extreme weather events	Destruction of facilities; loss of stock; loss of business; mass scale escape with the potential to impact on biodiversity	Encourage uptake of individual/cluster insurance; improve siting and design to minimize damage, loss and mass escapes; encourage use of indigenous species to minimize impacts on biodiversity, use non-reproducing stock in farming systems

Current biological and system technologies will need to be improved and new technologies developed. Genetic knowledge and management in aquaculture are not as developed as in other husbandries, and will be both a major challenge and an opportunity. Examples include genetic improvement for more efficient feeding and diet specificity, and for increasing species resistance to higher temperature, lower oxygen and pathogens. Since aquatic pathogen risks may be exacerbated by climate change, biosecurity and prevention measures may need to change accordingly. Early identification and detection mechanisms may need to be improved, and suitable treatment strategies and products developed.

Potential adaptation measures in post-harvest, distribution and markets

Both capture fisheries and aquaculture feed into diverse and spatially extensive networks of supply and trade that connect production with consumers, adding significant value and generating important levels of employment. To some extent, this system can be used to provide an important mediation and buffering function to increasing variability in supply and source location, but direct impacts will also affect its ability to do so. A range of issues and adaptation measures can be considered (see Table 3).

Table 3. Climate change-related impacts potential adaptation in post-harvest/distribution

Impact on post harvest, distribution/markets	Potential adaptation measures	Responsibility	Reactive/ Anticipatory
Reduced or more variable yields, supply timing	Source products more widely, change species, add value, reduce losses	Private	Either
	Develop more flexible location strategies to access materials	Private/public	Either
	Improve communications and distribution systems	Public/private	Either
	Reduce costs to increase efficiency	Private	Either
	Diversify livelihoods	Private	Either
Temperature, precipitation, other effects on post-harvest processes	Change or improve processes and technologies	Private/public	Either
	Improve forecasting, information	Public/private	Either
Vulnerability of infrastructure and communities to extreme events	Add new or improved physical defences, accommodation to change	Private/public	Either
	Rehabilitate infrastructure, design disaster response	Private/public	Reactive
	Set up early warning systems, education	Public/private	Anticipatory
Trade and market shocks	Diversify markets and products	Private/public	Either
	Provide information services for anticipation of price or market shocks	Public/private	Anticipatory

Management and institutional adaptations

Ecosystem approaches to fisheries (EAF) and to aquaculture (EAA) that embed precautionary approach applications within integrated management (IM) across all sectors have the potential to increase ecosystem and community resilience and provide valuable frameworks for dealing with climate change. This would create flexible management systems and support decision-making under uncertainty. However, it would require rapid adjustment of management tools and regulations as necessitated by changed conditions or circumstances.

In aquaculture, decisions about resource use, environmental capacity and biosecurity could be developed on a similar basis. In the post-harvest sector, issues such as food safety and spoilage management could likewise be addressed. Where aquaculture could be used for adaptation in other sectors, planning would be required at appropriate system and management scales, such as watersheds, and estuaries. These approaches would serve to provide guidance in understanding and minimizing perverse incentives that lead to overcapacity, overfishing, excessive environmental impact and other harmful practices while, at the same time, defining positive incentives to meet sustainable development goals.

Well defined sectoral performance criteria need to be set out to bring climate change threats, risks and potential adaptations within normal management practice. Public and private sector linkages and partnerships will be essential in developing efficient and effective responses. Market demands will be key mechanisms in supporting adaptation, and their impacts on equity among suppliers, intermediaries and consumers will need to be recognized and applied. Thus certification systems, including sustainability, organic, fair-trade and other criteria will need to be addressed more carefully in the context of climate change, and consider the potential for more vulnerable groups to take advantage of economic opportunity. Adaptation will need to contain strong mechanisms for equity, as increased competition may reduce access for poorer people and other vulnerable groups to production, employment and consumption.

CLIMATE CHANGE MITIGATION MEASURES IN FISHERIES AND AQUACULTURE

The primary mitigation route for the sector lies in its energy consumption, through fuel, raw material use and production. As with other food sectors, distribution, packaging and other supply chain components also will contribute to the sector's carbon footprint. Net mitigation contributions of fisheries, aquaculture and related supply chain features are small in overall terms but can be improved. In some cases, climate change mitigation would be complementary to and reinforce existing efforts to improve fisheries and aquaculture sustainability. However, when implementing such strategies, their possible negative impacts on food security and livelihoods would have to be better understood, justified where relevant, and minimized. There also may be valuable interactions for the sector with respect to environmental services such as maintaining the quality and function of coral reefs, coastal margins, inland watersheds, potential carbon sequestration and other nutrient management options, but these will need further research and development (R&D).

Greenhouse gas (GHG) impacts of the fisheries sector

Footprint of fisheries operations

Fisheries activities contribute to GHG emissions during capture operations and subsequently during the transport, processing and storage of product. Industrial fisheries have much greater emissions than small-scale fisheries, although most boat-based fisheries use motorized vessels and the subsector's fuel:CO_2 emissions ratio has been estimated at around 3 teragrams of CO_2 per million tonnes of fuel used. Fuel efficiency is defined primarily by motor, propulsion and gear characteristics, but is substantially affected by fisheries management and practice. Any management measures that encourage a "race to fish" create incentives to increase engine power. Overfished stocks at lower densities and smaller individual sizes require vessels to exert more effort, catch greater numbers of individual fish, travel to more distant or deeper grounds or fish over a wider area, all of which would increase fuel use per tonne of landings.

Footprint of aquaculture production

Compared to most other animal husbandry practices, aquaculture has a small overall CO_2 carbon foot print. The largest part of aquaculture production is based on freshwater herbivorous or omnivorous species such as carp, requiring at most small amounts of fertilizer, often organic, and in some cases, low-energy supplementary feeds. Although some species and systems, such as shrimp, salmon and marine carnivores, are a minor part of total production, they have high feed energy or system energy demands, and consequently very high footprints. However, even in these cases, the high quality food value, especially the essential fatty acid content, may need to be recognized.

The global warming potential (GWP) of other gases may also need to be considered. The GWP of methane is estimated to be 23 times that of CO_2, and the terrestrial livestock sector is estimated to account for 37 percent of all human-induced methane emissions. Although aquatic production systems (ricefields, wetlands, pond sediments) may also contribute, at so far undefined levels, farmed aquatic organisms do not themselves emit methane and so reduce its total GHG footprint per tonne.

Some developing countries focus aquaculture production on high value, but energy intensive species for export. This is very important for livelihoods and food security, but may be more subject to economic risks under climate change scenarios, and will require careful trade-off assessment for future development. Location and material flows also need to be explored for mitigation potential, as well as a shift or diversification to other species or other less energy consuming technologies.

Footprint of post harvest practices

As in all food production sectors, post-harvest activities entail stocking, packaging and transporting and they create post-consumption waste, all linked with CO_2 emissions. Of special note are those related to air transport. Intercontinental airfreight may emit 8.5 kg CO_2 per kg of fish shipped, about 3.5 times the levels from sea freight, and more than 90 times those from transport of fish consumed within 400 km of its source. Product form will also have an important effect, including energy embodied in packaging, and can influence options for maintaining quality and value with respect to transport method. There are important implications for fish trade, upon which many developing nations depend for valuable export earnings. In order to understand the carbon footprint of fishery products and define comparative performance and areas for potential improvement, emissions need to be traced throughout the entire supply chain, using a full life-cycle analysis (LCA) from harvest to post-consumer wastes. The carbon footprint of the sector also needs to be considered in comparison to that of other food production sectors.

Achievable mitigation measures

Mitigation in fisheries production systems

Although a relatively small global contributor, capture fisheries have a responsibility to limit GHG emissions as much as possible. For example, eliminating inefficient fleet structures (e.g. excessive capacity, over-fishing), improving fisheries management, reducing post-harvest losses and increasing waste recycling will decrease the sectors' CO_2 emissions and improve the aquatic ecosystems' ability to respond (assimilative capacity and resilience) to external shocks.

Other technical solutions to reduce fuel use, subject to clear analysis of options and production returns, might include shifting towards static fishing technologies and to more efficient vessels and gears. In some cases, win-win conditions could be identified, where reduced fuel-use strategies would link with reducing fishing effort, improving returns to vessels, safeguarding stocks and improving their resilience to climate change. These will need to be seen in the context of global forces impacting fisheries, such as changing fuel prices and increasing internationalization of fish trade, especially through air freight. Increases in fuel prices will tend to decrease fuel use while increases in internationalization will tend to increase fisheries' contributions to CO_2 emissions. Here, too, mitigation decisions need to consider the total system.

Mitigation in aquaculture production systems

As with capture fisheries, aquaculture's total GHG contributions are relatively small, but it has equal obligations for reducing impacts. Policies to support climate change mitigation need to be developed that address resource access and use, production options and market-related measures such as certification, encourage transparent measures of mitigation standards with comparison to other food producing sectors and, where appropriate, ensure suitable social inclusion and protection. As with fisheries, a full LCA approach would be required. Key areas for focus would include fishmeal, fish oil and other feed inputs, and water and energy efficiency, especially for small scale producers. Genetic modification technologies could have particular efficiency impacts through widening the production scope of low-impact aquaculture species, or making agricultural crop materials or waste products usable for growing carnivorous aquatic species. However, this would require evaluation on wider social and political criteria. Technologies and management approaches should be accessible to small and rural farmers.

Mitigation in post-harvest systems

Many key mitigation elements have already been noted with respect to capture fisheries and aquaculture production. Maximizing yield and quality, and reducing spoilage will have significant effects, if the technical measures used are, themselves, efficient. Improved infrastructures and market communication will help optimize supply to consumption linkages, and measures to increase local availability of aquatic products will reduce overall transport energy requirements, though they may need to be balanced against negative impacts on trade and economic opportunities for poorer groups.

Increasing awareness of carbon footprints and their context

The sustainability of fisheries and aquaculture is a priority issue for many fishery stakeholders, and the food security implications are critical development challenges. As concern grows about global change issues, carbon footprint awareness is increasing. Diverse stakeholders including consumers, industries and governments are becoming more conscious of the scientific, social responsibility, economic and development issues related to the aquatic value chain. There is a critical need for dialogue and collaboration on these issues among industry, government and the scientist community, as well as for increased awareness among all diverse stakeholders concerning the development choices to be made. The sector will need to engage with such increasing awareness and promote methods and products that meet strategic environmental objectives but also support social equity and basic access to food.

THE ROLE OF GOVERNANCE IN ADAPTATION AND MITIGATION

There is a critical need for well informed public policy to address mitigation of GHG emissions to limit and minimize impacts of climate change. The safeguarded benefits in the fisheries sector are an important factor to be considered. Sound public policy also will be required for climate change adaptation in order to reduce ecosystem vulnerability, provide information for planning and stimulating adaptation, and ensure that adaptation actions do not have negative effects on other ecosystem services and the longer term viability of fisheries and aquaculture.

The nature and risks of mal-adaptation – excessive and economically damaging responses to minimal or unsubstantiated risks, or inappropriate responses creating perverse incentives – also need to be better understood. In addition to the good governance principles currently applicable to the sector, agencies responsible for sectoral support and management would support climate change mitigation and adaptation in the sector by:

- building institutional and legal frameworks that consider and respond to climate change threats and uncertainties along with other pressures such as overfishing, pollution and changing hydrological conditions. This requires effective public, private and NGO partnerships, integrating research and management across the sectors and ensuring that regulations limiting access to resources are appropriate to respond to both the threats and benefits of future climate variability;

- moving rapidly towards full implementation of the Code of Conduct for Responsible Fisheries (CCRF), which encompasses the ecosystem approach to fisheries and aquaculture;
- establishing institutional mechanisms, such as bilateral and multilateral agreements – to enhance mobility of fishing activities within and across national boundaries to respond to changes in resource distribution and ensure transparent and competitive market arrangements are in place – which can only be recommended in the context of functional transboundary governance regimes and effective systems to control illegal, unreported and unregulated (IUU) fishing;
- enhancing resilience of fishing and aquaculture communities by supporting existing adaptive livelihood strategies and management institutions that are designed to support adaptation to climate change and variability, such as reciprocal access arrangements and conflict resolution mechanisms;
- exploring policies promoting local and regional consumption of aquatic products, versus export-oriented policies, as a form of mitigation, as well shifting or diversifying to other species or less energy-consuming technologies;
- supporting initiatives, such as property rights and other incentive mechanisms, to reduce fishing effort in overexploited fisheries, and linking these with the promotion of wider livelihood options, and appropriate financing instruments for change;
- eliminating harmful subsidies and perverse incentives, such as subsidizing fishing fleets under stress (through direct funding, cheaper fuel, or tax cuts) that serves to allow unprofitable fisheries to continue operating and further depresses the state of the fish stock(s);
- linking disaster risk management with development planning, especially concerning planning coastal or flood defences and applying “soft engineering” solutions where possible through conservation of natural storm barriers, floodplains and erodible shorelines in order to manage costs and damage impacts;
- conducting climate-change risk and social impact assessments when evaluating mitigation and adaptation alternatives and including analyses of distributional impacts of such alternatives;
- promoting research on short- and medium-term climate change impacts to support the identification of vulnerability hot spots and the development of adaptation and mitigation strategies, including financing and risk reduction mechanisms aimed at enabling integrated and broader national planning;
- addressing other issues contributing to vulnerability of the sector’s communities, such as access to markets and services, political representation and improved governance; and
- engaging in long-term adaptation planning, including promotion of fisheries- and aquaculture-related climate issues in Poverty Reduction Strategy Papers and National Adaptation Programs of Action, to address longer-term trends or potential large-scale shifts in resources or ecosystems.

CONSTRAINTS TO ADAPTATION AND MAL-ADAPTATIONS

The potential effects of climate change on aquatic organisms and their resources-dependent communities are complex. The general impacts of various scenarios on aquatic systems can be predicted but overall effects on the spawning cycle, migration pattern, natural mortality and community structure of aquatic organisms cannot be predicted. Regime shifts are expected to happen but even gradual changes in climate can provoke unpredictable biological response as ecosystems shift from one state to another. The unpredictability of both short- and medium-term effects on the ecosystem and the reactions of the communities impacted by these changes are major constraints to climate change response and adaptation by the fisheries sector. Conventional decision-making and planning approaches are frequently unreliable because of poor data, and uncertain and precautionary situations.

In many cases, even basic data that would provide understanding of the vulnerability of fisheries and aquaculture to climate change are lacking and, therefore, bases for prioritizing adaptive strategies are constrained. For example, the lack of data for most small island developing states, which would be expected to have very high vulnerability due to reliance on fisheries and low adaptive capacity, has prevented their inclusion in previous vulnerability mapping exercises. While neither vulnerable communities nor data insufficiencies are limited to developing countries, the lack of information is especially acute for them.

Short-term adaptations by fishing communities in response to environmental stresses can lead to their own long-term problems. For example, early responses to ecosystem change often include fishing harder, deeper, farther from home, in poorer weather or with changes in gear such as decreased mesh sizes. These may increase catches initially but will have long-term consequences of increased and broader impacts to marine systems which further erode their ability to adapt to climate (and other) changes.

For aquaculture, the availability of fish meal and fish-oil-based feeds will be a major constraint to growth. The shift towards vegetable materials would need to take into account potential scarcities due to water stress as well as competition with food and biofuel demand. Such trade-offs need to be clearly understood at regional and local levels. The use of primary production by herbivorous fish needs to be better quantified and understood at local and regional scales to ensure that their use provides effective adaptation to climate change. The conditions and performance potential of integrated systems also need to be better defined and understood.

Finally, the response of markets to these changes and the implications for prices, economic returns and sector investment will have major impacts on sectoral performance, employment, food security and longer-term development impact. Information on the drivers of these markets, particularly in highly competitive, internationalized contexts, and the production and quality standards, and certification criteria by which products are defined are still limited. The context for which policy changes can accommodate climate change while still addressing equity issues and delivering acceptable levels of poverty alleviation and food security is even less well understood and needs clear and committed focus.