Building resilience for adaptation to climate change in the fisheries and aquaculture sector

Cassandra De Young, Doris Soto, Tarub Bahri and David Brown
Fisheries Department, FAO, Rome

INTRODUCTION
It is often overlooked that over 500 million people depend, directly or indirectly, on fisheries and aquaculture for their livelihoods. In addition, fish provide essential nutrition for over 4 billion people and at least 50 percent of animal protein and essential minerals to 400 million people in the poorest countries. Trade is also an important characteristic of the fisheries and aquaculture: fish products are among the most widely traded foods, with more than 37 percent by volume of world production traded internationally. But climate change is bringing an ocean of change to the world’s fisheries, which are already in crisis from overfishing and poor management.

Multiple drivers of change and the role of climate change
Change, whether positive or negative, is an integral part of fisheries and aquaculture systems and comprises those drivers that will impact the aquatic systems' biological processes through, for example, changes in water quantity and quality, temperature, salinity, oxygen, acidity, fishing pressure and natural habitats, as well as drivers of change that impact human choices in their use of aquatic resources, such as changes in governance structures, input and output prices, technological change, emergencies and cultural contexts. If not integrated into the management system, the impacts of these drivers of change may be profoundly negative on long-term sustainability – many capture fisheries worldwide have declined sharply in recent decades or have already collapsed from overfishing. Climate change will compound existing pressures on fisheries and aquaculture and the question of how to meet increasing demand for fish in the face of climate change poses a great challenge to fisheries and aquaculture management.

Since most aquatic animals are cold-blooded, their metabolic rates are strongly affected by environmental conditions, especially temperature. Changes in temperature can have significant influence on the reproductive cycles of fish, including the speed at which they reach...
sexual maturity, the timing of spawning and the size of the eggs they lay. The projected increasing temperatures will likely result in changes in distribution of both freshwater and marine species, with most marine species ranges being driven towards the poles, expanding the range of warmer-water species and contracting that of colder-water species. Examples of temperature-related impacts specific to aquaculture would be related to temperature comfort zones of farmed species and the increased spread of farmed fish diseases directly linked to increased temperatures. Whether positive or negative, these changes will have social and economic impacts on the fisheries and aquaculture industries and communities – possibly through new mismatches between where the fishing happens and where it is landed or processed, changes in farm profitability either through inputs needed or productivity of individual farms, or through the disappearance of traditional sources of local food and livelihood security. At the macro scale, there will likely be implications for international fisheries management owing to changes in the distribution of transboundary fish stocks, for example.

Greenhouse gas (GHG) accumulation is also increasing the acidification of oceans, with potentially severe consequences for shellfish and squid, mangroves, tropical coral reefs and cold-water corals. Among other services, coral reefs are home to 25 percent of all marine fish species, but changes in water chemistry may directly impact on their ability to produce their skeletons, directly impacting reef-based fisheries alongside tourism, medicine, etc.

**Rising sea levels** will displace brackish and fresh waters in river deltas, wiping out some freshwater aquaculture practices and destroying wetlands, but also creating new environments and some opportunities (e.g. for brackish aquaculture species). **Increased storm activity** (intensity and occurrence) endangers the lives of fishers, fishfarmers and coastal/riparian/lacustrine communities directly, can cause damage to fisheries and aquaculture infrastructure and housing, and presents additional threats for coral reefs and mangroves. More subtly, storms stir waters, causing temperatures and nutrients levels to change along the water column, having likely consequences for species distribution. Storms and floods will also increase the risks that farmed species escape, having potential impacts on farm profitability and genetic biodiversity in the natural systems.

Fisheries- and aquaculture-dependent economies, coastal communities and fishers and fishfarmers are expected to experience the effects of climate change in a variety of ways. In addition to climate change impacts not stemming from the aquatic systems that they may face, such as increased risks of human diseases relating to increased temperatures, these communities are closely tied to changes in the aquatic world. These might include: displacement and migration of human populations from low-lying areas to less risky areas or to follow changes in fish distributions; effects on coastal communities and infrastructure due to sea level rise; and increased losses throughout the production and distribution chain owing to changes in the frequency, distribution or intensity of weather events. It must be noted that many fishing and coastal communities already subsist in precarious and vulnerable conditions because of poverty and rural underdevelopment, with their well-being often undermined by overexploitation of fishery resources and degraded ecosystems. As the vulnerability of fisheries and fishing communities depends not only on their exposure and sensitivity to change, but also on the often lacking ability of individuals or systems to anticipate and adapt, these communities tend to be among the most vulnerable.
In addition, as nations implement adaptation and GHG mitigation actions across all sectors, there may also be unplanned consequences (trade-offs and synergies) of actions in other sectors that drive changes within the aquatic food production systems. For example, national GHG mitigation efforts may include the development of aquatic renewable energy sources, such as through capturing energy in tides, currents, waves, wind, hydropower and aquatic biofuels. How these mitigation strategies impact the aquatic systems is not always

**BOX 1**

**Predicted changes in fisheries catch potential**

Results of a modelling exercise on the latitudinal shift in catch under different greenhouse gas concentrations scenarios indicate that there could be drastic changes, with the tropical countries suffering up to a 40 percent drop in catch potential and high-altitude regions enjoying as much as a 30 to 70 percent increase in catch potential.

Change in maximum marine catch potential from 2005 to 2055 under the climate change scenario where greenhouse gas concentrations are doubled by the year 2100

How would the current top fishing countries fare under this high emissions scenario? The model predicted that, by 2055, exclusive economic zones (EEZ) average catch potentials in Nordic countries (such as Norway, Greenland and Iceland) would increase by 18 to 45 percent; in the Alaska and Russia Pacific EEZ by around 20 percent, and decline by various degrees in most EEZ around the world, with Indonesia having the largest projected decline of the group – an over 20 percent decline across the 45 species currently targeted within its EEZ.

*Source: Cheung et al. (2010).*

In addition, as nations implement adaptation and GHG mitigation actions across all sectors, there may also be unplanned consequences (trade-offs and synergies) of actions in other sectors that drive changes within the aquatic food production systems. For example, national GHG mitigation efforts may include the development of aquatic renewable energy sources, such as through capturing energy in tides, currents, waves, wind, hydropower and aquatic biofuels. How these mitigation strategies impact the aquatic systems is not always
well understood but, for example, the building of dams for hydropower could undermine fisheries and aquaculture systems downstream as water flows will be greatly altered. Drivers of change stemming from the need of other sectors to adapt to climate change will also arise. For example, agriculture production in areas faced with increasing water scarcity may need to divert water for irrigation purposes, impacting lake and river water levels and flows. In addition, the often open access nature of fisheries lends itself to being a planned or unplanned adaptation strategy for other sectors. For example, by 2007, 80 percent of conflict-affected refugees in the Democratic Republic of the Congo were successfully living from fishery and agriculture activities after receiving training in the new skill sets (UNHCR, 2007) and aquaculture is often looked to as a potential adaptation alternative for fisheries in the face of decline catches. From the unplanned side, “emergency fishing” is a common strategy for displaced persons (see FAO, 2007, for example). How these actions change, for example, water availability or quality and productivity or ecosystem functioning will need to be monitored and planned for.\(^2\)

**VULNERABILITIES TO CHANGE**

According to IPCC (2001), vulnerability to change is a function not only of the degree of exposure to climate change but also of the sensitivity of a system to changes in climate – “the degree to which a system will respond to a given change in climate, including beneficial and harmful effects” and adaptive capacity – “the degree to which adjustments in

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\(^2\) See, for example, Leonhard, Stenberg and Stottrup (2011) for an assessment of impacts of offshore wind farming on fish communities.
practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate”. Given that fisheries and aquaculture are part of a complex social–ecological system, there is no one set method for putting the IPCC vulnerability model into practice. The application of the IPCC model will depend on who’s vulnerability is of interest for adaptation planning, at what scale is the adaptation planning to take place, as well as other pragmatic factors such as data availability. For example, Allison et al. (2009) were interested in the vulnerability of national economies to climate change implications to fisheries (see Box 2). Alternatively, one might be interested in the vulnerability of species, food webs or ecosystems (see Bell et al., 2011 for examples of tuna, tuna food web, coral reef, mangroves, freshwater habitats and fisheries vulnerabilities in the tropical Pacific islands). Cinner et al. (2012) have applied the IPCC model to social-ecological coral reef-based fishing communities, imbedding the coral reef vulnerability to climate change into the fishing communities’ vulnerability to changes stemming from within the coral reef systems.

Although adaptation planning can happen given a rapid appraisal approach to understanding vulnerabilities, the more detailed and in-depth the vulnerability analysis, the better targeted the adaptation planning. For example, recent community-level vulnerability work within 29 reef-dependent coastal communities across five western Indian Ocean countries showed large differences in adaptive capacities across the communities when facing the same climate change impact; requiring “nuanced” policy interventions to reduce vulnerability within each community (Cinner et al., 2012). Within communities, there will also be vulnerability differences by age, gender and marginalized groups, so, ensuring that the vulnerability assessment includes these individuals will also provide better targeted adaptation planning.

What is interesting to note is that, even in the face of positive opportunities stemming from climate change, those vulnerable to change may not be able to take advantage of these potential benefits, whether it be, perhaps, because of lack of knowledge or access to new markets or overly rigid management system.

**PREPARING AND RESPONDING TO THE IMPACTS: ADAPTATION TO CLIMATE CHANGE THROUGH BROADER VULNERABILITY REDUCTION**

Although determining a direct causal relationship between climate change and impacts on fisheries and aquaculture may not often be feasible owing to costs of research or complexity of the system under question, there is already much that can be done within a “no regrets” approach to reducing vulnerability. Fortunately, we are not without knowledge on how to build and maintain resilience of the natural and human systems and, in the fisheries and aquaculture sector, there is no lack of guidance – the 1995 Code of Conduct for Responsible Fisheries (FAO, 1995) clearly demonstrates the principles and standards applicable to the conservation, management and development of the world’s fisheries, including aquaculture, such as the prevention of overfishing, the minimization of negative impacts to aquatic ecosystems, and the protection of marine and coastal habitats.

Although the resilience concept is often limited to the ability of a system to “bounce back” to its previous state when faced with a shock, it is often the case that simply returning to the status quo is not enough and efforts to improve the ecological, social and economic well-being of the system before and after shocks must happen. Building back better is a term used in disaster risk management to reflect the need to not only respond to emergencies but to put in place disaster risk management that better prepares for the next potential emergency (http://www.preventionweb.net/files/13247_i0772e001.pdf).
ecosystems and local communities, and the protection of human rights to a secure and just livelihood. The ecosystem approach to fisheries and aquaculture (EAF/EAA) (see FAO 2003, 2009b; 2010), provides the approach, strategies and tools for implementing the Code and implies a holistic, integrated and participatory way to managing fisheries and aquaculture systems (see Box 3).
USING EAF/EAA TO IDENTIFY KEY CLIMATE CHANGE ISSUES

As the EAF/EAA calls for a broader and more holistic approach to analysis and management actions, the EAF/EAA process itself assists in the monitoring of climate change impacts. A key step in any EAF/EAA process includes the identification of issues (and their prioritization through a risk assessment) that need to be addressed by management, including all direct and indirect impacts of the fishery/farm on the broader system. Included in this process is the identification of any non-fisheries/aquaculture issues (those that are external to the fisheries/aquaculture management system) that are affecting, or
could in the future affect, the performance of the system and its management such as climate variability and change (see Figure 2). Having the broadened and integrated monitoring system that an EAF/EAA would imply would allow for the monitoring of changes in the aquatic ecosystems and their impact pathways through the fisheries and aquaculture systems.

**USING EAF/EAA TO BUILD RESILIENCE TO CLIMATE CHANGE**

To build resilience to the effects of climate change and to derive sustainable benefits, fisheries and aquaculture managers, as a top priority, need to adopt and adhere to best practices such as those described in the FAO Code of Conduct for Responsible Fisheries and the EAF/EAA. Progress in this direction would be an important contribution to maintaining biodiversity, preserving the resilience of human and aquatic systems to change, and improving our capacity to anticipate and adapt to inevitable climate induced changes in aquatic ecosystems and the related fisheries production systems. Some direct potential benefits of implementing the EAF/EAA include:

- creating resilient ecosystems, human, and governance communities through (i) decreasing the exposure of the sector by increasing the aquatic systems’ resilience, (ii) decreasing the communities’ sensitivities to change; as well as by (iii) increasing the sector’s adaptive capacity;
• supporting intersectoral collaboration (e.g. integrating fisheries and aquaculture into national climate change adaptation and disaster risk management (DRM) strategies and supporting integrated resource management, such as integrated coastal zone or watershed management, water planning);
• promoting integrated monitoring and information systems - incorporating scientific and local knowledge sources;
• improving general awareness of climate change within and outside the sector;
• promoting context specific and community-based adaptation strategies;
• avoiding “mal-adaptations” (e.g. overly rigid fishing access regimes that inhibit fisher migrations, adaptation actions that would increase fishing effort in an over-fished fishery);
• embracing adaptive management, decision-making under uncertainty and the precautionary approach; and
• Promoting natural barriers and defenses rather than hard barriers that would impact the ecosystem.

Improving the general resilience of the fisheries and aquaculture system will reduce its vulnerability to climate change. For example, biodiversity rich systems are less sensitive to change than overfished and biodiversity-poor systems. Healthy coral reef and mangroves systems provide, inter alia, natural barriers to physical impacts. Fisheries and aquaculture-dependent communities with strong social systems and a portfolio of livelihood options have higher adaptive capacities and lower sensitivities to change. Larger-scale production systems under effective governance systems and having high capital mobility would tend to be more resilient to change.

In addition, by assisting in improving our understanding about the role of aquatic systems as natural carbon sinks and how fisheries impact this role, and by supporting a move to environmentally friendly and fuel-efficient fishing, aquaculture and post-harvest practices, implementing the EAF/EAA will also feed into global greenhouse gas mitigation efforts.

Interestingly, a recent modelling exercise (Merino et al., 2012) to determine the capacity of the global fisheries and aquaculture sector to meet increasing demand for fish products while facing the high emissions scenario of the IPCC (A1B) concluded that meeting current and larger consumption rates is feasible but only if fish resources are managed sustainably and the animal feeds’ industry reduces its reliance on wild fish. The authors note a strong caveat that ineffective fisheries management and rising fishmeal prices driven by greater demand could, however, compromise future aquaculture production and the availability of fish products. Putting into place robust and effective management now is the key to meeting future and uncertain challenges.

PLANNED ADAPTATION
In addition to restoring and building up of the ecological system’s natural resilience, the fisheries and aquaculture sector may also rely to a certain extent on risk spreading or reduction tactics, such as livelihood diversification, disease and disaster risk management, and creative combinations of public and private insurance tools. At a different scale, traditional policy and management planning and tools will need to be “climate proofed”, such as by
allowing spatial and temporal tools – protected areas and closed seasons, for example – to adapt to climatic variables or by explicitly incorporating decision-making under uncertainty into management plans. Management planning will need to evaluate, for example, how shifts from an open access situation towards defined and stable access rights might affect fishers’ use of migration as an adaptation strategy when facing changes in species distributions. At the regional level, regional agreements among countries sharing transboundary stocks will also need to be adjusted as shifts in stock distributions and changes in productivity occur.

Technical innovation will also provide some adaptation options, such as the breeding of saline resistant aquaculture species to confront sea level rise, the development of storm resistant fish farming systems (e.g. sturdier fish cages) and the widespread use of information technology to share weather as well as market information. Fishing vessels of all sizes may be rendered more stable to allow for fishing further away from the coastal area to follow targeted species and resist inclement weather. Fish aggregating devices may be used to lure fish back within the traditional fishing grounds.

Proper aquaculture zoning mechanisms at the watershed level, biosecurity frameworks, risk analysis and strategic environmental assessments (FAO, 2009c) that take into account the added effects on aquaculture farms would enable the sector to better face potential threats such as new diseases, invasive species and eutrophication-related problems that can be exacerbated by climate change (e.g. increased water temperature and salinity).

Diversification within aquaculture, and especially exploring new opportunities in mariculture, potentially offers new adaptation options. By moving away from freshwater systems, both the impacts on water resources and the competition with other sectors for its use would be reduced. Further aquaculture movement off the coast and offshore can reduce impacts on coastal zone habitats and competition with other users (e.g. tourism) but a greater exposure to rougher seas would be a trade-off to such an adaptation action.

Tables 1 and 2 present examples of adaptation options available within fisheries and aquaculture, the choice of which would depend on the context at hand and the social, economic and ecological costs and benefits.

CONCLUSIONS
Climate change is adding to the sense of urgency within fisheries and aquaculture for the need to improve the resilience of human and aquatic systems. The Code of Conduct for Responsible Fisheries and the Ecosystem Approach to Fisheries and Aquaculture provide many principles, strategies and tools that can be implemented today to lessen these socio-ecological systems’ exposure and sensitivity to climatic change as well as increasing their adaptive capacities.

Application of the EAF/EAA will help to ensure that effective stakeholder involvement in both monitoring changes and adaptation planning becomes the default approach to ensuring resilience of the socio-ecological systems and to minimize unintended

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4 See, for example, Badjeck et al. (2009) for a review of institutions and management frameworks under climate change in Peru.
5 See, for example, the proposal of Bell, Johnson and Hobday (2011) on ways to adjust an existing regional tuna fishing effort scheme in the face of climate change-related shifts in tuna distribution.
consequences of adaptation and mitigation actions. Integrated adaptation planning and implementation within a systems approach will not only allow for the specificity needed within each sector but also for addressing issues shared across sectors within a broader system.

We will need to continue efforts to improve and downscale our understanding of current vulnerabilities and adaptation strategies of the sector to prepare the sector for its own climate change planning and also to enable the sector to participate in national climate change planning, including providing feedback on the impacts of adaptation and mitigation actions from other sectors.

Technological innovation, public and private insurance schemes and disaster risk management will also provide necessary adaptation options but putting into place robust and effective management now will be the key to ensuring and enhancing the benefits derived from fisheries and aquaculture.

<table>
<thead>
<tr>
<th>Impact on fisheries</th>
<th>Potential adaptation measures</th>
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<tbody>
<tr>
<td>Reduced fisheries productivity and yields</td>
<td>Access higher value markets  Increase effort or fishing power*</td>
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<tr>
<td>Increased variability of yield</td>
<td>Diversify livelihood portfolio  Insurance schemes  Precautionary management for resilient ecosystems  Implementation of integrated and adaptive management</td>
</tr>
<tr>
<td>Change in distribution of fisheries</td>
<td>Private research and development and investments in technologies to predict migration routes and availability of commercial fish stocks*  Migration*</td>
</tr>
<tr>
<td>Reduced profitability</td>
<td>Reduce costs to increase efficiency  Diversify livelihoods  Exit the fishery for other livelihoods/investments</td>
</tr>
<tr>
<td>Increased vulnerability of coastal, riparian and floodplain communities and infrastructure to flooding, sea level and surges</td>
<td>Hard defences*  Managed retreat/accommodation  Rehabilitation and disaster response  Integrated coastal management  Infrastructure provision (e.g. protecting harbours and landing sites)  Early warning systems and education  Post-disaster recovery  Assisted migration</td>
</tr>
<tr>
<td>Increased risks associated with fishing (e.g. safety at sea)</td>
<td>Private insurance of capital equipment  Adjustments in insurance markets  Insurance underwriting  Weather warning system  Investment in improved vessel stability/safety  Compensation for impacts</td>
</tr>
<tr>
<td>Trade and market shocks</td>
<td>Diversification of markets and products  Information services for anticipation of price and market shocks</td>
</tr>
<tr>
<td>Displacement of population leading to influx of new fishers</td>
<td>Support for existing local management institutions</td>
</tr>
<tr>
<td>Various</td>
<td>Publicly available research and development</td>
</tr>
</tbody>
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*Adaptations to declining/variable yields that directly risk exacerbating overexploitation of fisheries by increasing fishing pressure or impacting habitats.  
Source: Daw et al. (2009).
Table 2: Example of adaptation to climate impacts on aquaculture

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Adaptive measures</th>
</tr>
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<tbody>
<tr>
<td>Temperature rise above optimal range of tolerance</td>
<td>Better feeds; selective breeding for higher temperature tolerance</td>
</tr>
<tr>
<td>Temperature change increased growth rates; higher production</td>
<td>Increase feed input and better management</td>
</tr>
<tr>
<td>Eutrophication and upwelling; mortality of stock</td>
<td>Better planning: farm/cage siting conforming to ecosystem carrying capacity, regular monitoring</td>
</tr>
<tr>
<td>Increased virulence of dormant pathogens</td>
<td>None; monitoring to prevent health risks</td>
</tr>
<tr>
<td>Limitations on fishmeal &amp; fish oil supplies/price</td>
<td>Fishmeal &amp; fish oil replacement; new forms of feed management; shift to non-carnivorous commodities</td>
</tr>
<tr>
<td>Coral reef destruction</td>
<td>None; but shifting from harvesting to breeding of coral reef species may impact positively by reducing fishing pressure and harmful fishing practices; improving reef resilience</td>
</tr>
<tr>
<td>Salt water intrusion</td>
<td>Shift upstream stenohaline species-costly; new euryhaline species in old facilities</td>
</tr>
<tr>
<td>Loss of agricultural land</td>
<td>Provide alternative livelihoods-aquaculture: capacity building and infrastructure</td>
</tr>
<tr>
<td>Reduced catches from artisanal coastal fisheries; loss of income to fishers</td>
<td>Reduced feed supply; but encourages use of pellet feeds-higher cost/ environmentally less degrading</td>
</tr>
<tr>
<td>Increase of harmful algal blooms</td>
<td>Mortality and increased human health risks by eating cultured molluscs</td>
</tr>
<tr>
<td>Indirect influence on estuarine aquaculture through changes in brook stock and seed availability</td>
<td>None</td>
</tr>
<tr>
<td>Impact on calcareous shell formation/deposition</td>
<td>None</td>
</tr>
<tr>
<td>Limitations for water abstraction</td>
<td>Improve efficacy of water usage; encourage non-consumptive water use aquaculture, e.g. cage-based aquaculture and/or mariculture</td>
</tr>
<tr>
<td>Water retention period reduced</td>
<td>Use of fast growing fish species; increase efficacy of water-sharing with primary users e.g. irrigation of rice paddy</td>
</tr>
<tr>
<td>Availability of wild seed stocks reduced/period changed</td>
<td>Shift to artificially propagated seed; extra cost</td>
</tr>
<tr>
<td>Destruction of facilities; loss of stock; mass scale escapement with the potential to impacts on biodiversity</td>
<td>Encourage uptake of individual/cluster insurance; improve design to minimize mass escapement; encourage use of indigenous species to minimize impacts on biodiversity</td>
</tr>
</tbody>
</table>

Source: De Silva and Soto (2009).

REFERENCES


