MODULE 10:

CLIMATE-SMART FISHERIES AND AQUACULTURE

Overview

This module looks at the climate-Smart Agriculture (CSA) concept from the perspective of the fisheries and aquaculture sector. Organized into six sections, the module provides an overview of the contributions made by the fisheries and aquaculture sector, the climate change impacts pathways that are affecting the sector and the vulnerabilities currently undermining resilience in aquatic systems. The ecosystem approach to fisheries and aquaculture (EAF/EAA) is presented as the underlying approach to developing climate-smart fisheries and aquaculture. Actions that support this approach are: sustainably increasing output productivity and efficiency within the sector; reducing the sector's vulnerability and increasing its resilience to change; and reducing and removing greenhouse gases (GHG) from within the sector. The module presents options for supporting these actions at different levels (national, regional, subsector, individual enterprise and community). The module concludes with an evaluation of the sector's progress towards CSA and the elements that support the successful transition to CSA. Boxes are used throughout the module to provide concrete examples of CSA actions and approaches.

Key messages

- Fisheries and aquaculture provide essential nutrition, support livelihoods and contribute to national development. However, the sector is facing significant challenges in maintaining its crucial contribution to these areas. Increasing global demand for fish and aquatic foods, ocean acidification and climate variability and change will only add to these challenges.
- Climate-smart fisheries and aquaculture will require: improving efficiency in the use of natural resources to produce fish and aquatic foods; maintaining the resilience aquatic systems and the communities that rely on them to allow the sector to continue contributing to sustainable development; and gaining an understanding of the ways to reduce effectively the vulnerability of those most likely to be negatively impacted by climate change.
- There is no lack of guidance for the sector. The Code of Conduct for Responsible Fisheries and the ecosystem approach to fisheries and aquaculture outline the principles and approaches that are central to ensuring the sustainability of the sector. However, the application of these principles and approaches is not keeping pace with the increasing need for their implementation.
- The general understanding of the implications of climate variability and change is improving. However, information on local-level impacts and vulnerabilities is lacking, which hampers adaptation planning. Improved capacities for decision-making under uncertainty are required.
- Examples of win-win tactics for attaining CSA objectives that are available to the sector include: the reduction of excess capacity and the implementation of fishing activities that are linked with improved fisheries management and healthy stocks; increased production efficiency through better integrated systems; improved feeding and reduced losses from disease in aquaculture; the reduction of post-harvest and production losses; and the further development of regional trade.
- The transition to CSA in fisheries and aquaculture will need to take place at all levels (individual,

business, community, national and regional) and time scales. All stakeholders from private and public sectors will need to be involved in the development of context-specific options to ensure the fisheries and aquaculture sector is climate-smart.

- To make the transition to CSA in fisheries and aquaculture, it will be necessary to ensure that the most vulnerable states, production systems, communities and stakeholders have the potential to develop and apply CSA approaches.
- Markets and trade may help buffer the impact of changes in production that affect food security, consumer prices and supply-demand gaps. However, the implications of climate change impacts and climate change policies on the entire supply and value chain need to be better understood. Appropriate policy measures need to be defined and implemented.

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10. 1 Introduction

This module addresses the following questions: What are the implications of climate change for the sector in relation to food security, nutrition and livelihoods? How can resilience be built and vulnerability be reduced within fisheries and aquaculture systems? What role does the sector need to do to reduce its greenhouse gas (GHG) emissions, provide alternative sources of energy and support aquatic systems' natural GHG sequestration and storage services?

The significance of fisheries and aquaculture

Fisheries and aquaculture support the incomes and livelihoods of 660-820 million people, about 10-12 percent of the world's population. The sector has an important role to play in gender equality, poverty and food security. With global fish supply over 150 million tonnes, more than 85 percent of this supply is used directly for food; supplying 15 percent of the world's protein and essential nutrition for around 4.3 billion consumers (FAO, 2012). The sector generates first sale values of over US$ 218 billion annually, and about 38 percent of production is traded internationally (FAO, 2012). Aquatic systems are also associated with rich biological diversity – with at least 27 000 species of fish, shellfish and aquatic plants, in a wide variety of ecosystems, so far identified (FAO, 2010a).

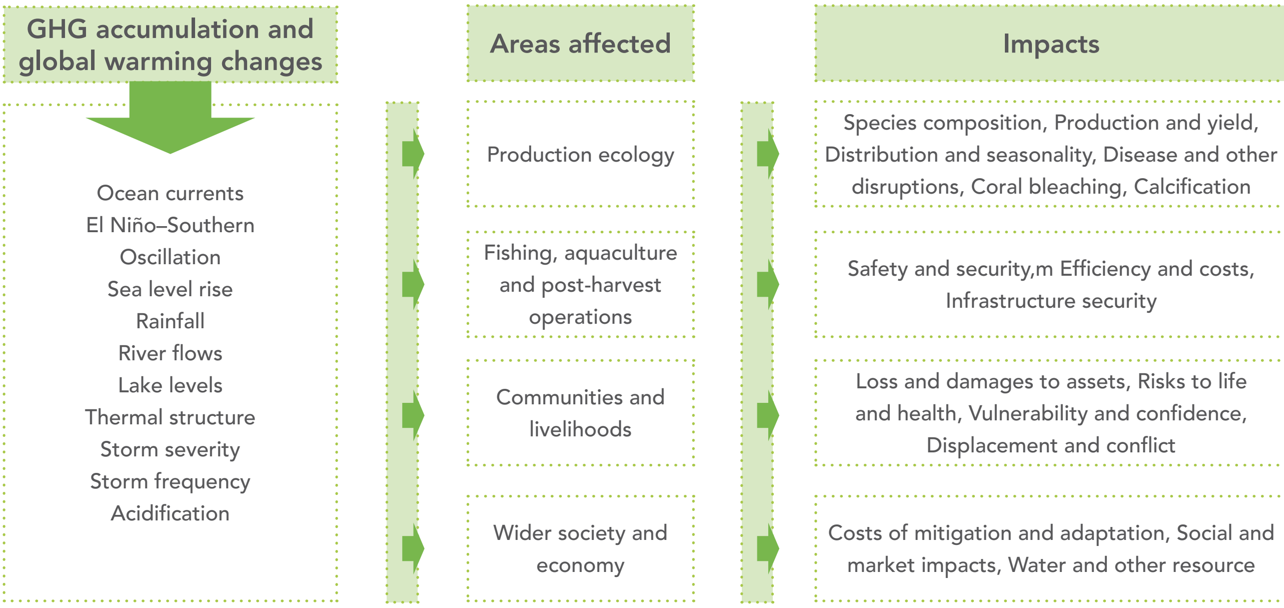
The global population is expected to increase to 9-10 billion by 2050. Expanding populations will create greater demand for aquatic foods, and the importance of fisheries resources and production systems will increase. However, there are significant concerns for the health of these resources with approximately 30 percent of assessed stocks estimated to be overexploited and global fish catches static or even declining (FAO, 2011). Consequently, aquaculture will have to satisfy much of the future demand for aquatic foods. To meet this demand, the aquaculture sector may need to increase production by 70-100 percent over current levels in the next two decades. However, aquaculture also faces increasing constraints as competition for land, water, energy and feed resources becomes more acute. These factors, combined with potential impacts of ocean acidification and climate change on ecosystems and on dependent communities, present significant challenges to the entire sector (Brander, 2007). The successful and continued delivery of benefits from fisheries and aquaculture will require the development of clearly targeted policies, sound management, technical changes and investments.

Climate change processes and impacts

The impacts of the accumulation of GHGs in the atmosphere and water relate to a number of physical phenomena including gradual changes in water temperature, acidification of water bodies, changes in ocean currents and rising sea levels. These physical changes affect ecological functions within aquatic systems and the frequency, intensity and location of extreme weather events (Cochrane *et al.*, 2009). A range of impacts on fisheries and aquaculture, both direct and indirect, can be expected. These are illustrated in Figure 10.1.

Ecosystem productivity is likely to be reduced in most tropical and subtropical oceans, seas and lakes. In high-latitude ecosystems, productivity is likely to increase (see Box 10.1). Physiological and behavioral processes of fish and the organisms they feed on will also be affected. The impacts, both positive and negative, will depend on the region and latitude. There is increasing evidence that global warming is already modifying the distribution of marine species. Warm-water species are being displaced towards the poles and experiencing changes in their size and the productivity of their habitats.

Figure 10.1
Example potential climate change impact pathways for fisheries and aquaculture

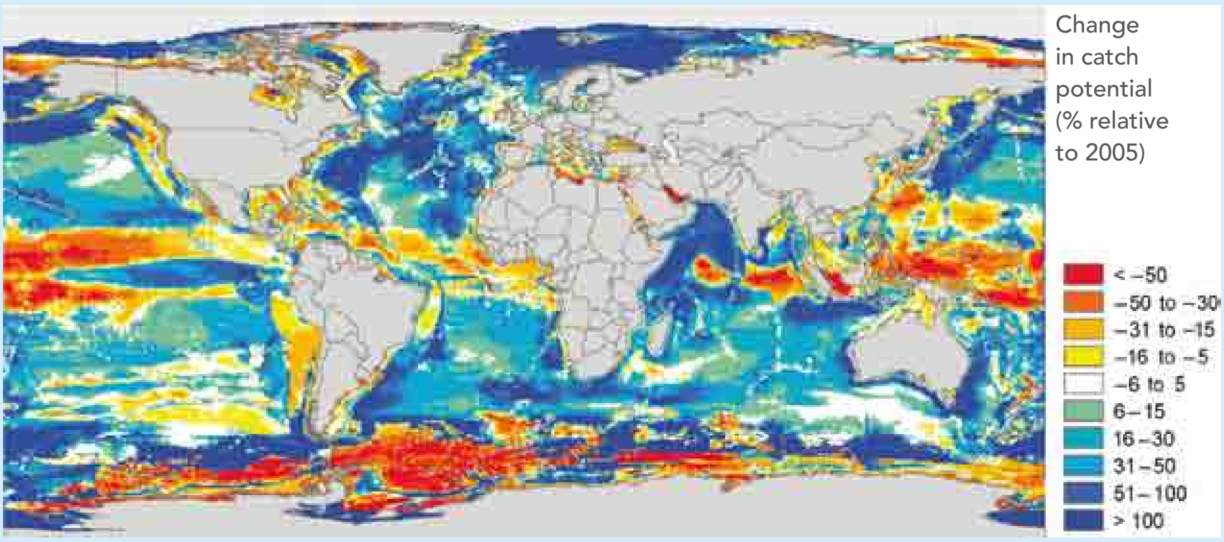


Source: developed from Badjeck *et al.*, 2010

Box 10.1
Predicted changes in fisheries catch potential between 2005-2055 under a higher GHG emissions scenario

Results of a modeling exercise on the latitudinal shift in catch under different GHG scenarios indicate that there could be drastic changes in the potential fisheries catch. Tropical countries could face up to a 40 percent drop in catch potential. High-latitude regions could enjoy as much as a 30 to 70 percent increase in catch potential.

How would the current top fishing countries fare under this scenario? The model predicted that, by 2055, exclusive economic zones (EEZ) average catch potentials in Nordic countries (such as Greenland [Denmark], Iceland and Norway) would increase by 18 to 45 percent; in the Alaskan (USA) and Russian Pacific EEZ by around 20 percent. In most EEZs around the world catch potentials would decline by various degrees, with Indonesia having the largest projected decline: over 20 percent across the 45 species currently targeted within its EEZ.



Source: Cheung *et al.*, 2009

Rising sea levels will displace brackish and fresh waters in delta zones and wipe out a range of productive agricultural practices. This will also destroy wetlands and have an impact on freshwater fisheries and aquaculture. On the other hand, higher sea levels may also create new environments and opportunities for the fisheries and aquaculture sector (e.g. for coastal aquaculture and mangrove development). Increased frequency and intensity of storms could directly endanger people and communities on coasts and damage housing, community facilities and infrastructure used for fisheries and aquaculture. Inland, the impacts on freshwater fisheries and aquaculture are also expected to be significant with increased variability in rainfall patterns as well as air and water temperatures affecting the productivity of rivers, lakes and floodplains. These impacts will also have a critical relationship with the use of freshwater resources for agriculture, industry, energy generation and urban water supplies (Ficke *et al.*, 2007). For aquaculture, broader changes in hydrological conditions and seasonal changes in temperature, pH, salinity and ecosystem health are all expected to change productivity and increase risks. To address these changes, some production systems may need to be relocated. Impacts on post-harvest activities, on value addition and on the distribution of fish to local, national and global markets may also be significant, with potential changes in location and variability of supplies, and changes in access to other key inputs, such as energy and water for processing. All of these quantitative and spatial changes will occur at the same time as other global socio-economic pressures are exerted on natural resources. All of this will have wider impacts on food security, habitation and social stability.

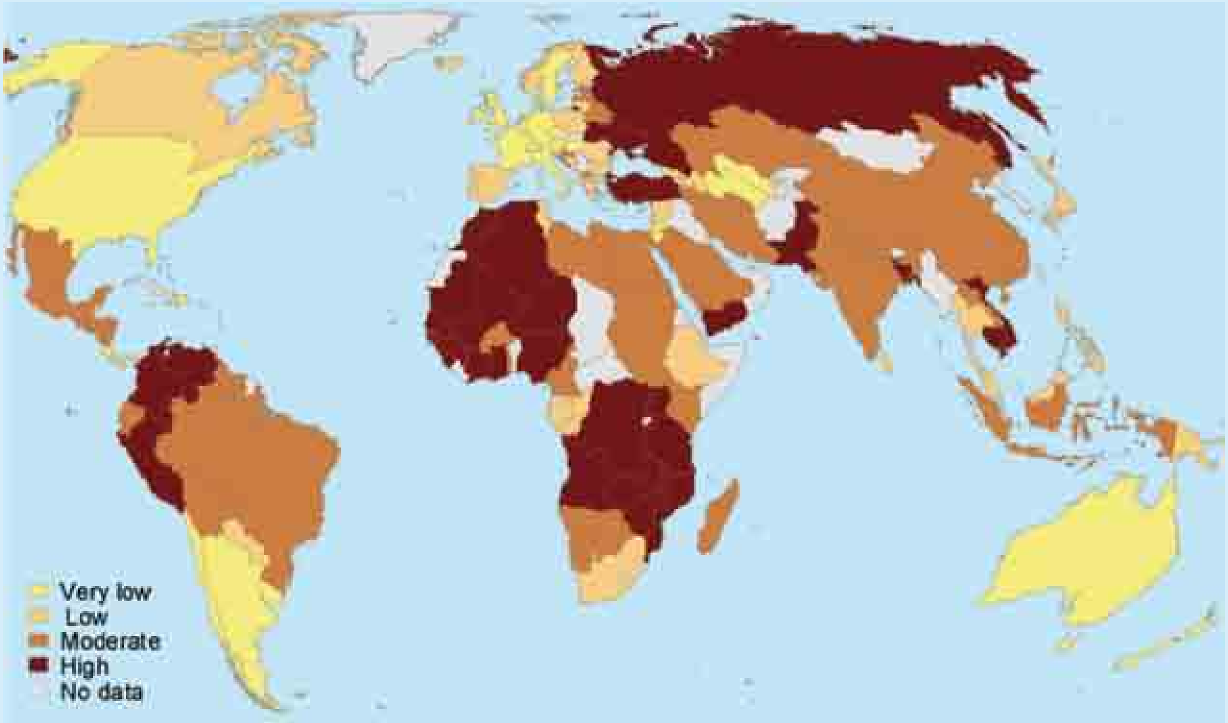
People, communities and vulnerability

According to the Intergovernmental Panel on Climate Change (IPCC), vulnerability to change is a function of the degree of exposure to climate change, the sensitivity of a system to such changes and the adaptive capacity of the system (IPCC, 2001; more on risks, vulnerabilities and resilience in Module 1). What vulnerability means to fisheries and aquaculture will depend on a variety of factors including: whose vulnerability is of concern; the scale at which adaptation planning is to take place; and the availability of data. Thus Allison *et al.*, (2009) described the vulnerability of national economies through climate change potential impacts arising in their fisheries (see Box 10.3), while Bell *et al.,* (2011) focused on the vulnerability of species, food webs and ecosystems, and explored the issues related to tunas, their food web, coral reefs, mangroves, freshwater habitats and fisheries activities in the tropical Pacific islands. Cinner *et al.* (2012) built upon the IPCC model by imbedding the vulnerability of coral reef systems to climate change into measures of coral reef-dependent fishing communities' vulnerability in order to capture the links between the human and aquatic systems.

Fisheries- and aquaculture-dependent economies, as well as coastal and riparian communities, are likely to experience a range of effects of climate change. Impacts will include those that are associated with changes in the resource base, such as shifts away from traditional fishing grounds or changes in available fish species. There will also be direct risks to fishers, farmers and coastal communities due to sea level rise, stronger sea surges and changes in the frequency, distribution or intensity of tropical storms. Surrounding the changes in the aquatic food production system will also be a range of other impacts, such as increased risks of human diseases related to increased air and water temperatures. Climate change will also have an impact on food security, social services, social cohesion, and human displacement and migration. Many fishing and coastal communities already subsist in precarious and vulnerable conditions due to poverty and rural underdevelopment. The well-being of these communities is often undermined by poor access to capital, limited skills, the overexploitation of fish stocks, other natural resources and degraded ecosystems. As noted above, the vulnerability of fisheries, aquaculture and fishing communities depends not only on their exposure and sensitivity to change, but also on the uncertain ability of individuals or systems to anticipate these changes and adapt. The distribution of the bulk of the world's aquaculture production in the tropics, where population densities are high, makes the sector especially vulnerable (De Silva and Soto, 2009).

Box 10.2
Global mapping of national economies' vulnerability to climate change impacts through fisheries

Following the IPCC definition of vulnerability and using available data, national economies' relative vulnerability to climate change impacts through their fisheries was calculated for 132 countries. The analysis revealed that 16 African least developed countries (LDC) and three Asian LDC were among the highly vulnerable countries. Unfortunately, limited data precluded many small island developing states from being included in the analysis. However, given their high dependence on fisheries, low adaptive capacity and high exposure to extreme events, they are also likely to be among the more vulnerable countries.



While many African marine coastal fisheries are not likely to face huge physical impacts, the region's adaptive capacity to respond to climate change is relatively low and fish consumption high. As a result, economies there are highly vulnerable even to minor changes in climate and temperature. In the northern hemisphere, Russian and Ukrainian economies were ranked highly vulnerable due to a predicted high degree of warming impacting fisheries in this region and low adaptive capacities.

Sources: Allison *et al.*, 2009 and Daw *et al.*, 2009

10.2 Climate-smart approaches

Strategies for developing climate-smart approaches for fisheries and aquaculture are broadly similar to those for other sectors. As described elsewhere in this sourcebook, these strategies are connected with most, if not all, of the major cross-cutting themes of development and environment. As in other sectors, a number of issues need to be recognised and reconciled in order for the 'climate-smart' approach to become the default approach for development. Key considerations include the need to:

- respond to considerable increases in global demand for aquatic food in the face of climate change and other factors, and address specific issues of food access and livelihoods, across the entire supply, value and benefit chains;
- absorb effectively emerging technologies and adapt to market and socially driven changes within and around the sector;

- identify specific gaps in capacity, efficiency, and system resilience for the sector, and particularly those which are potentially likely to increase under climate stress, and identify generic or specific actions to address these gaps;
- address options for better policy and management integration within and across the sector, in terms of understanding the function and flows of goods and services from the aquatic systems as well as defining efficient use of these resources;
- connect effectively with related development objectives, such as hunger eradication, poverty alleviation, resource protection and rehabilitation, nutritional safety and health, personal and community empowerment, self-determination and vulnerability reduction; and
- develop approaches that are clearly recognizable and actionable by policy agents to work effectively with practitioners and beneficiaries at all levels and are based on clear evidence of functionality and effectiveness.
- In addressing these issues, there are many lessons to be learned from other sectors. However, fisheries and aquaculture have distinct characteristics, including:
- the significant level of social and economic dependence on wild fish stocks in small- and large-scale ecosystems, which are interacting with a wide range of activities that are driving climate change;
- the continued challenge of governance issues, particularly for fisheries resources, including the substantial levels of IUU (illegal, unreported and unregulated) fisheries, widespread fleet overcapacity in many fisheries, and potentially conflicted management environments;
- the transboundary nature of major resource systems, including areas beyond national jurisdiction (ABNJ), and the political complexity of resource management systems;
- specific issues of ecosystem complexity, with multiple-scale interactions of seascapes, watersheds and landscapes, uncertainties of change and impacts, and the difficulty of developing robust and practical models that are accessible to users;
- the high concentration of aquaculture around the tropics and in very populated areas;
- social issues related to the 'last-resort' or emergency uses of fisheries resources[1], as well as the widespread social marginalisation and poverty in fishing communities along many of the supply chains;
- the particularly rapid interactions of pollutants and pathogens in aquatic environments that are being acted upon by various drivers of acidification and climate change and the potential risks to productivity, stocks and human health;
- very limited development of risk and insurance markets for the sector, particularly for capture fisheries, and few mechanisms for community-based responses to less stable conditions; and
- data scarcity and difficulties in obtaining data in complex, highly heterogeneous, social, economic and ecological systems, and the challenge of creating a common understanding of important issues across these different systems and stakeholders.

In such a complex environment of human-ecosystem interactions, fully causal and quantitative relationships between climate variability, climate change and its impacts on fisheries and aquaculture cannot realistically be established. However, much can be done to reduce vulnerability using practical approaches, and there is considerable knowledge on how to build and maintain the resilience[2] of natural ecosystems and the human communities that inhabit them. In the fisheries and aquaculture sector, there is no lack of guidance in this area – the FAO Code of Conduct for Responsible Fisheries demonstrates the principles and standards applicable to the conservation, management and development of the world's fisheries, including aquaculture (FAO, 1995). These principles and standards cover issues such as the prevention of overfishing, the minimization of negative impacts to aquatic ecosystems and local communities, and the protection of human rights for a secure and

[1] In times of drought (emergency in agriculture), fisheries is used as an emergency food security source. Understanding the importance of this role will be necessary in cross-sectoral adaptation planning.

[2] 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 are needed to improve the ecological, social and economic well-being of the system before and after shocks. Building back better is a term that has been used in DRM to reflect the need not only to respond to emergencies but to put in place DRM that better prepares for the next potential emergency (FAO, 2009c).

just livelihood. The ecosystem approach to fisheries and aquaculture (EAF/EAA)[3] provides the strategies and tools for implementing the FAO Code and implies a holistic, integrated and participatory approach to managing fisheries and aquaculture systems (see Box 10.4).

Box 10.3
A brief overview of the ecosystem approach to fisheries and aquaculture

The EAF/EAA is a holistic strategy for managing capture fisheries and aquaculture in ways that integrate ecological, socio-economic and institutional dimensions. The EAF/EAA focuses on fisheries and aquaculture management, but its perspective covers more than a narrow focus on the production and management of commercially important species. The EAF/EAA includes interactions between the core of the productive fish system and the people who depend on it, as well as the system's other social and ecological elements. It is aligned with more general ecosystem approaches and supports the sector's contributions to broader multi-sectoral applications.

The purpose of the EAF/EAA is to plan, develop and manage fisheries and aquaculture in a manner that addresses different societies' multiple needs and aspirations, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by aquatic ecosystems. EAF/EAA strives to balance diverse societal objectives by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated management approach within ecologically meaningful boundaries.

Within the overall objectives of human and ecosystem well-being, the application of the EAF/EAA should address the following principles:

- apply the precautionary approach when faced with uncertainty;
- use the best available knowledge, whether scientific or traditional;
- acknowledge multiple objectives and values of ecosystem services;
- embrace adaptive management;
- broaden stakeholder participation with due consideration to gender;
- ensure equitable distribution of benefits from resource use; and
- promote sectoral integration and interdisciplinarity.

Sources: FAO, 2003 and 2009b

As EAF/EAA calls for a broader and more holistic approach to analysis and management actions (Figures 10.2 and 10.3), the process itself can assist in monitoring climate change and its impacts.

Using EAF/EAA's broad and integrated monitoring system would allow for the monitoring of changes in the aquatic ecosystems and their impacts pathways through the fisheries and aquaculture systems. A key step in any EAF/EAA process includes the identification of issues (and their prioritisation through a risk assessment) that need to be addressed by management, including all direct and indirect impacts of production, processing and supply chains on the broader aquatic and coastal systems. Also covered in this process is the identification of any non-sector issues (external to the management system), such as global demand, input prices, climate variability and change, that are affecting, or could affect in the future, the performance of the system and its management.

[3] See FAO 2003, 2009b and 2010b.

Figure 10.2
Using the EAF issue identification process to identify climate change impacts

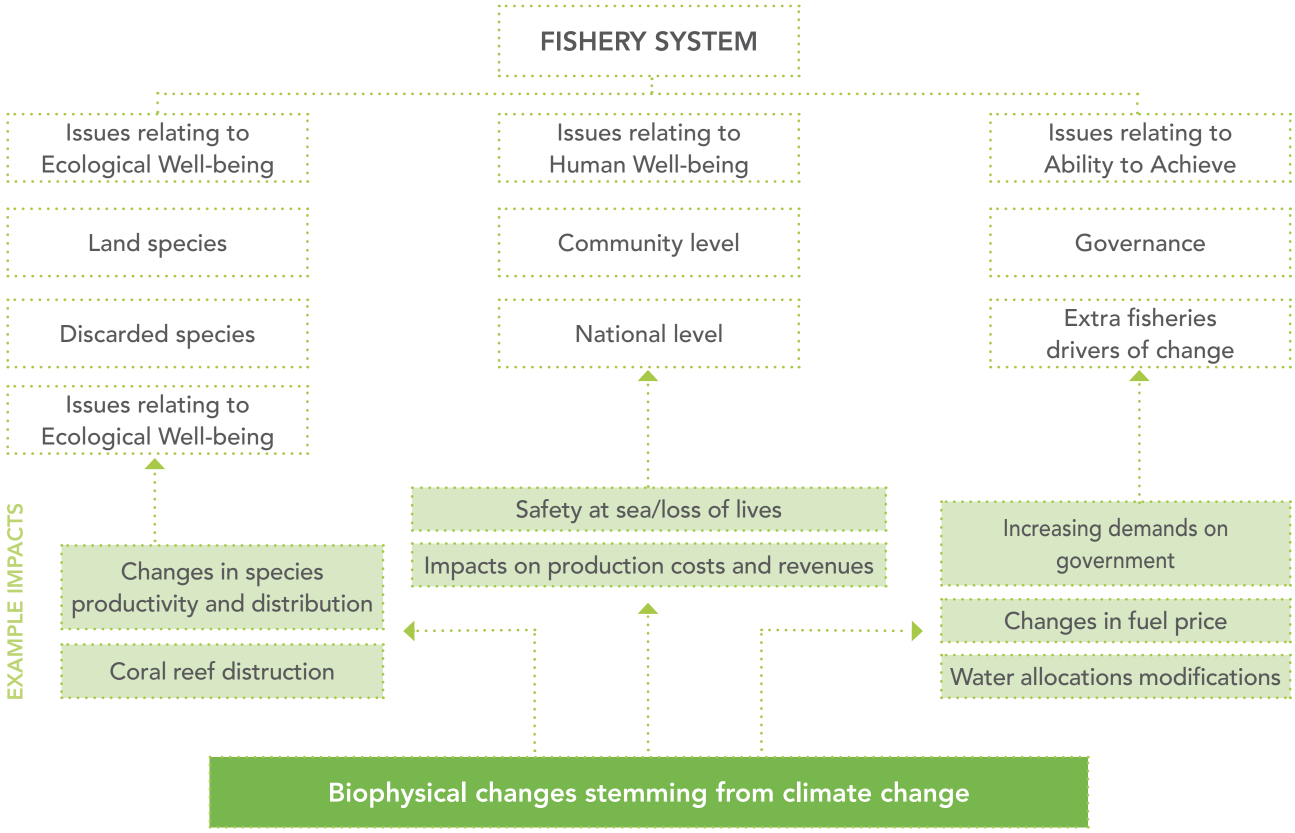
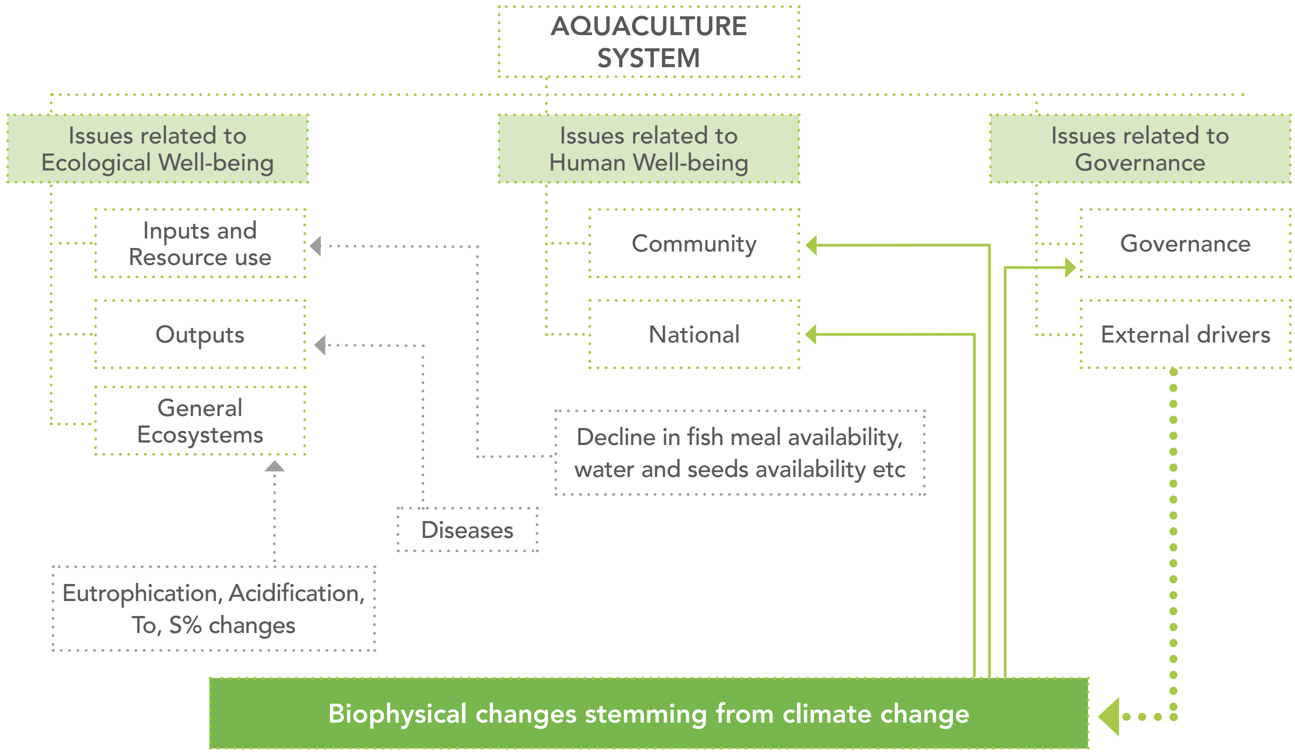


Figure 10.3
Using the EAA issue identification process to identify climate change impacts



Continuous green lines represent similar impacts to those described for fisheries.

Using EAF/EAA to build resilience to climate change

To build the resilience of the fisheries and aquaculture sector to the effects of climate change and to ensure the sector delivers sustainable benefits, it is essential to adopt and adhere to best practices such as those requested by the FAO Code of Conduct for Responsible Fisheries and whose implementation is facilitated by the EAF/EAA. Making progress in this direction would contribute to maintaining biodiversity, preserve the resilience of human and aquatic systems to change, and improve the capacity to anticipate and adapt to climate-induced changes in ecosystems and fisheries production systems. Direct benefits of implementing the EAF/EAA include:

- supporting ecosystems, communities and governance structures that are resilient by: decreasing the exposure of the sector by increasing the aquatic systems' potential to absorb and recover from change; decreasing the human communities' sensitivities to change; and increasing the sector's adaptive capacity;
- improving the efficient use of natural and human resources for food and livelihood security;
- supporting inter-sectoral 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 and water planning);
- promoting integrated monitoring and information systems that incorporate scientific and local knowledge sources;
- improving general awareness of climate change inside and outside the sector;
- promoting context-specific and community-based adaptation strategies;
- avoiding 'maladaptations' (e.g. overly rigid fishing access regimes that inhibit fisher migrations and adaptation actions that would increase fishing in an overfished fishery);
- embracing adaptive management, decision-making under uncertainty and the precautionary approach; and
- promoting natural barriers and defences rather than hard barriers that would affect the ecosystem.

Improving the general resilience of fisheries and aquaculture systems will reduce their vulnerability to climate change. Biodiversity-rich systems may be less sensitive to change than overfished and biodiversity-poor systems. Healthy coral reef and mangroves systems can provide many benefits, including 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 with effective governance structures and adequate mobility of capital tend to be more resilient to change.

10.3 Practical themes for developing climate-smart fisheries and aquaculture

Three key interlinking objectives for developing climate-smart fisheries and aquaculture are discussed below. The first objective is connected closely to the broader food sector goal of sustainable intensification. It concerns the provision of the primary means by which outputs can be expanded without placing excessive pressure on fishery resources, including land, water, feed and fertilizing inputs. The second objective focuses on the need to reduce the vulnerability associated with climate change impacts and to build the resilience required to cope effectively with potential changes over the longer term. The final area concerns the means by which the sector can be more strongly engaged in GHG mitigation processes.

Theme 1: Sustainably increasing output productivity/efficiency

There are two principle approaches for increasing productivity and efficiency. For capture fisheries, the essential issues are the reduction of excess capacity and ensuring the fishing effort is linked with improved fisheries management and the maintenance of healthy and productive stocks and systems. Though total output might not be increased to any significant extent, costs could be reduced, particularly fuel costs, and economic efficiency would improve. Better stock conditions may also improve the catch quality. The better use of by-catch would also enhance sectoral performance. By applying ecosystem approaches to resource management, climate change impacts can be better accommodated into management responses. This would reduce the potential risks of overfishing and the collapse of key stocks. For aquaculture the issues of increasing output and efficiency are more similar to those of agriculture. The primary emphasis is on intensifying production, using better integrated systems, improving stocks, making feeding more efficient and reducing losses from disease (De Silva and Soto, 2009). Dependence on fishmeal and oil is often cited as a primary constraint to future outputs and growth for aquaculture. This dependence is declining as alternative feeds are being developed and as a wider range of species is being cultivated at lower trophic levels that are closer to the levels of primary production (Tacon and Metian, 2008). However, it is increasingly likely that there will be constraints related to land and water resources in both inland and coastal areas. These constraints are due to competition from other sectors and changing agro-ecological conditions, which in some cases may lead to the relocation of the production system.

More broadly across the sector, efforts should be made in reducing losses and wastes, increasing yields and productivity in fish and aquatic food processing and other areas where value can be added, and enhancing efficiencies in product distribution. The overarching principles of sustainable approaches for expanding output are found in the FAO Code of Conduct for Responsible Fisheries. These principles may be progressively elaborated upon with more specific guidance as climate-smart experience is gained. Tools and best practices for improving social, economic and ecological efficiency and sustainability are under development.

Box 10.4
The environmental costs of New Zealand food production

Hilborn and Tellier (2012) offer a comparative environmental overview of fisheries production systems. In New Zealand, when compared with dairy and meat production, fisheries had a lower impact in terms of water and fertilizer use, eutrophication potential and antibiotics. Most fisheries also had lower GHG production levels than the meat industry, and some were lower than those for average dairy production. The dairy and meat industries were more efficient in energy inputs and production per unit, but the good state of major fish stocks ensured relatively efficient fuel consumption scores. The New Zealand quota management system also discouraged excessive vessel capacity and largely eliminated competitive open access fishing, which reduced fuel consumption. The New Zealand dairy and meat industries were more efficient in energy use and GHG production than comparable industries around the world. The authors attribute this relative efficiency to high year-round productivity and the ability to raise both dairy animals and other livestock on pasture for most of the year, which reduces the need to use feed crops.

Environmental indicators per 40 g protein portion in New Zealand food production systems

	Inputs						Outputs		
	Energy	Fresh Water	Fertilizer	Pesticides	Antibiotics	Surface Area Impacted	GHG gases	Eutrophication potential*	Acidification potential**
	(Megajoules)	(litres)	(g)	(kg)	(mg)	(m^2)	(kg CO_2)	(g)	(g)
NZ Dairy	1.56	171	26	24	1.17	1.24	0.86	3	8.4
NZ Meat	4.9	262	188	129	1.17	18.14	3.7	13.3	36.8
NZ Squid	7.11	0	0	n/a	0	17	0.62	1.7	3.9
NZ Hoki	7.11	0	0	n/a	0	100	0.64	1.7	4
NZ Jack Mackerel	7.69	0	0	n/a	0	57	0.68	1.8	4.3
NZ Rock Lobster	99.53	0	0	n/a	0	n/a	8.75	23.6	55.1
NZ Orange Roughy	14.4	0	0	n/a	0	104	1.27	3.4	8
NZ Barracouta	5.55	0	0	n/a	0	n/a	0.49	1.3	3.1
NZ Southern Blue Whiting	5.88	0	0	n/a	0	24	0.52	1.4	3.3
NZ Ling	7.26	0	0	n/a	0	36	0.64	1.7	4
NZ Snapper	12.6	0	0	n/a	0	n/a	1.11	3	7

* Eutrophication potential = measure used in life cycle assessment to calculate impacts due to excessive levels of macronutrients in the environment caused by emissions of nutrients to air, water and soil. Expressed as equivalent kg of phosphate (PO4).

** Acidification potential = contribution to acidic substances to air, water and soils that are implicated in a range of environmental threats including acid rain, soil acidification and changing pH of soils and water. Typical substances are: sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3). Expressed as tonnes of SO_2 equivalents.

Source: Hilborn and Tellier, 2012

Some specific technical and management measures can be identified to improve efficiency and broaden production and supply options under changing conditions. However, the potential to apply these measures, and the context in which the relevant decisions are made, will be strongly influenced by the availability of data and information, and the means by which these data may be securely interpreted and used. In changing physicochemical, bioecological and socioeconomic conditions, making data and information accessible to all stakeholders in a timely manner becomes a major challenge. This is especially the case in areas with fewer resources, where issues may be more critical and the capacity to address them is more limited. The difficulties and costs of assessing aquatic systems pose an additional burden. The development of effective adaptive management strategies in data poor situations is a special challenge that must be overcome across the fisheries and aquaculture sector.

Theme 2: Reducing vulnerability and increasing resilience

As with other food sectors, there are a number of aspects to vulnerability in the fisheries and aquaculture sector. These range from the specific issues related to individual households and communities to the more strategic areas dealing with sustaining industry performance and national food supply. The impacts of climate change are potentially significant and will require specific responses. These responses will have to address both the increasing risks of human, physical, social and financial losses associated with short-term events, and strategic investments and operational changes required to adjust to longer-term change. Social and economic vulnerability is already a concern in a number of communities that are dependent on fisheries and aquaculture, particularly those involved in small-scale production. Building climate-inclusive resilience is a recognised need. For the commercial sector, increased uncertainties of supply, associated with impacts on stocks and their distribution and production risks in aquaculture, add to financial vulnerability within the supply and value chain. These impacts may be felt in the national food supply, food security and trade.

Specific issues for fisheries and aquaculture

There are a range of generic risks for the sector that are associated with climate change. However, the incidence and severity of these risks are yet to be determined. As mentioned above, a range of negative outcomes are expected. These will involve direct physicochemical and bioecological impacts, as well as social, economic and political consequences. Effective and well measured protection against these outcomes will be a major challenge. There may also be positive opportunities in fisheries, as changing conditions may improve ecosystem functions and increase productivity. Rising sea levels could create more opportunities for aquaculture in salinised coastal margins and higher temperatures could improve conditions for cultivating local stocks. Climate change may also put stresses on some pathogens or predators, which might also improve productivity. With regards to the processing of fish and aquatic animals, changing stock or production locations in some cases might also improve rather than reduce distribution efficiency. Better or more consistent catches of key species in specific locations could improve local profitability. Consequently, the impact of climate change on markets and economies may be either negative or positive. However, in most scenarios, even if net outputs across an ecosystem or region are relatively stable, changing spatial and economic distributions of supply and demand will create an additional development burden. This burden will be particularly felt by poorer or more vulnerable groups.

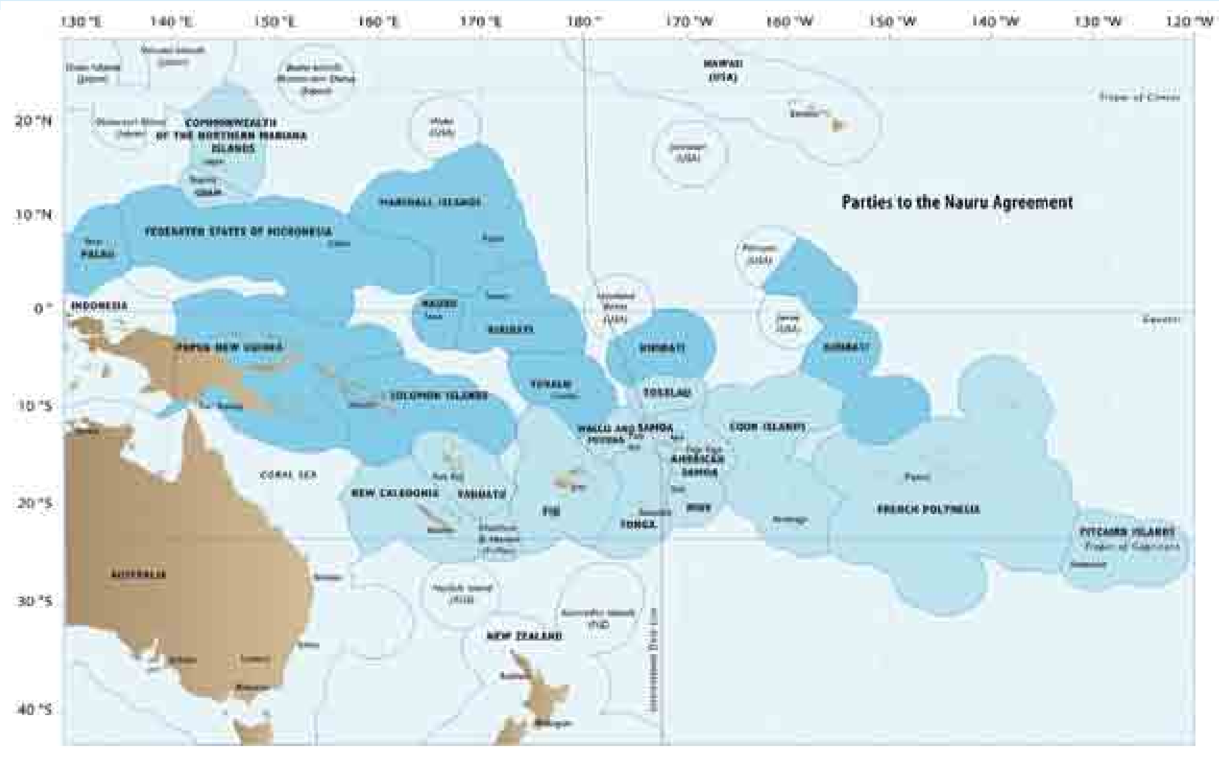
Changing locations, management and data needs, social and policy responses will all require effective institutional arrangements. Change will also need to be made in current systems, and new systems will need to be developed. For transboundary resources, changing species mixes and location characteristics may require new and adaptive systems of management and more effective operational procedures, and the need for effective resource management in ABNJ will become increasingly important. More generally, the processes currently being advocated for fisheries reform will need to be taken up to reduce excess fishing pressure, improve efficiency and returns to fishing enterprises and incorporate uncertainty into decision-making. These actions would sustain supplies and, at the same time, maintain or enhance the essential human and social capital that is created through adequate access to food and employment in small-scale fisheries.

Box 10.5
Climate-smart tuna fishing in the western Pacific

The industrial purse seine fisheries for skipjack and yellowfin tuna in the equatorial waters of the western Pacific Ocean make important contributions to global fish supplies. They are also vital to the economies of Pacific Island countries (PICs). The 1.3 million tonnes of tuna caught each year from the EEZs of PICs supply 25 percent of the world's canned tuna. Licence fees from foreign fishing fleets contribute up to 10-40 percent of government revenue for several small island nations. Locally based tuna fishing vessels and canneries account for as much as 20 percent of the gross domestic product of some PICs.

The effects of the El Niño Southern Oscillation (ENSO) on the distribution and abundance of these species make it difficult to know when and where the benefits derived from these fisheries will be greatest. During La Niña events, tuna catches are highest in the western part of the region. During El Niño episodes, the best catches are made further east. To keep catches within sustainable bounds, and optimise distribution of economic benefits, the eight PICs where most of the tuna are caught control and distribute the fishing effort through the 'vessel day scheme' (VDS). These eight countries are known as the Parties to the Nauru Agreement (PNA).

The exclusive economic zones of the PNA, which produce 25 percent of the world's canned tuna.



PNA members are: Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands and Tuvalu (PNA, 2013)

The VDS sets a total allowable effort within PNA waters. This is allocated among the EEZs of PNA members, based on historical average patterns of fishing. Members are able to trade fishing days between themselves to accommodate situations where fish, and hence vessels, are unusually concentrated either in the west or east due to ENSO events. The VDS is therefore similar to the 'cap and trade' schemes designed to limit emissions of carbon dioxide. The trading component aims to ensure that all PNA members continue to receive some level of benefits from the fishery, regardless of where tuna are concentrated.

The VDS not only deals with climatic variation, it has the flexibility to allow the fishery to adapt to climate change. Allocation of vessel days to PNA members based on fishing effort history is adjusted regularly. As the projected redistribution of tuna to the east occurs under the changing climate, the periodic adjustment of allocated vessel days will reduce the need for members to trade fishing days.

Source: Bell *et al.*, 2011

In a number of contexts, interactions with other sectors, themselves affected by climate change, are also likely to be important. Inland fisheries are particularly sensitive to policies and actions outside the sector. In the same vein, many coastal environments are also increasingly subject to changes in freshwater runoff, agricultural intensification, growth in the industrial and energy sector, expanded urbanization, transport and tourism development. For aquaculture, there are similar issues of interaction and tradeoffs with other sectors, particularly regarding land and water use, aquatic and terrestrially derived feeds, and the negotiation of coastal space.

Defining and valuing the role and needs of the fisheries and aquaculture sector, raising awareness about the sector and negotiating balanced outcomes across sectors are key challenges (see Module 2 on landscape approach). There may also be important issues for GHG mitigation, which would be best addressed through integrated sectoral approaches.

Box 10.6
Options for culture based fisheries to improve climate resilience

Culture-based fisheries (CBF) is typically a perennial and seasonal stock enhancement process. It is practiced in smaller water bodies that under normal conditions are incapable of supporting a fishery through natural recruitment. In CBF, the stocked fish are managed communally with ownership rights. It therefore falls within the realm of aquaculture. Recently, the practice has gained momentum due to the increasing demand for fish and improvements in seed stock production and availability. CBF has also become a major part of government strategies to increase food fish production and improve livelihoods, particularly in impoverished rural communities (Amarasinghe and Nguyen, 2009).

CBF as an environmentally friendly food production system
In many instances, CBF is seen as a practice with a small environmental footprint and a good example of multiple, effective use of water resources (De Silva, 2003).

CBF does not consume water or external feed resources. The only input is the seed stock. The stocked species are selected in such a manner that all food niches are filled and that the natural food production is adequate to maintain growth and well-being of the stock. Consequently, the yields are much less than in most intensive aquaculture practices. However, CFB is environmentally friendly and the cost input is minimal with no feed related GHG contribution. This semi-intensive to extensive form of aquaculture often utilizes communal water bodies. For governments in developing countries, the practice is an attractive means for increasing food fish production and food security among rural communities.

The possibilities of the stocked fish mingling with wild counterparts are higher than in normal aquaculture practices. For this reason, whenever possible, indigenous fish species are advised for CBF. Also, hatchery bred stocks should originate from well managed broodstocks. Ideally, the broodstocks would originate from wild stocks; however, some form of risk assessment is always recommended before stocking.

In China, it is estimated that in 2008 CBF contributed to a catch increase of 120 000 tonnes, with a value of US$ 225 million. The cost/benefit ratio of resource enhancement is around 1:5. This translates into 1.5 million professional fishers increasing their profits by US$ 150 per capita. The large-scale jellyfish release programme carried out in China's Liaoning Province significantly increased the catch of jellyfish. In 2009, the catch volume reached 23 500 tonnes. As a result, 130 000 fishers increased their profits by nearly US$ 150 per capita (Liu, 2009).

CBF sensitivity to climate change and adaptation potential
The stocking and harvesting in CBF is almost entirely dictated by the elements. Stocking is best done when the water body is at full supply level, and harvesting takes place when the water level recedes. As a result, the practice will be affected by climate change, particularly changes in rainfall patterns. Also, in areas where a large number of water bodies are used for CBF, there could be an unexpected glut in the availability of food fish. Consequently, there will be a need to put in place strategies to minimize these effects through staggered harvesting and a coordinated marketing strategy. If done using an ecosystem perspective, good climate forecasting and proper CBF planning are climate-smart strategies. Watershed authorities or lake and reservoir authorities should be aware of CBF practices in order to improve water management and ensure the coordinated use of water resources.

Understanding and reducing vulnerability
Vulnerability to climate change in the sector is experienced across a range of productive, social and political dimensions and will also depend on timing and locations of changes. For example, climate risks may be felt

at a very specific location and in a targeted manner (e.g. through increased storm events in a small fishing location), or at a broader scale, as in the impacts of a shift in temperature and freshwater balances across a major river delta and its associated coastal system, or as a range of risks impacting on a range of people and communities with different capacities to cope with and adapt to the potential impacts. As with other sectors, vulnerability is also highly connected with other factors, such as the availability of human, social and political capital, access to services and other resources, and options for alternative livelihoods. Options for reducing vulnerability are commonly defined by the nature and severity of the risks involved; the comparative costs of physical and other responses required to reduce impacts by definable amounts; and the capacity of individuals, communities and organizations to analyse, prioritize and implement the appropriate actions.

Tools and best practices for reducing vulnerability in specific conditions are still being developed and validated within the fisheries and aquaculture sector. However, in addition to the general resilience-building actions described in the following section, a number of practical options can be identified. These are outlined in Table 10.1.

Table 10.1
Overview of practical options for reducing vulnerability in fisheries and aquaculture

Impact area	Potential responses
Capture fisheries	
Reduced yield	Access higher value markets; shift/widen targeted species; increase fishing capacity/effort; reduce costs/increase efficiency; diversify livelihoods, exit fishery
Increased yield variability	Diversify livelihoods; implement insurance schemes; promote adaptive management frameworks
Change in distribution	Migrate fishing effort/strategies and processing/distribution facilities; implement flexible allocation and access schemes
Sea level change, flooding, and surges	New/improved physical defences; managed retreat/accommodation; rehabilitation and disaster response Integrated coastal management; early warning systems and education
Increased dangers of fishing	Weather warning systems; improved vessel stability/safety/communications
Social disruptions/ new fisher influx	Support existing/develop new local management institutions; diversify livelihoods.
Aquaculture	
Extreme weather events	Improve farm siting and design; individual/cluster insurance; use indigenous or non-reproducing stocks to minimize biodiversity impacts;
Temperature rise	Better water management, feeds, handling; selective breeding/genetic improvements; adjust harvest and market schedules
Water stress and drought conditions	Improve efficacy of water usage; shift to coastal aquaculture, culture based fisheries; select for short-cycle production; improve water sharing; improve seed quality, efficiency,
Sea level rise and other circulation changes	Shift sensitive species upstream; introduce marine or euryhaline species (wide salinity tolerance); use hatchery seed, protect broodstock and nursery habitats,
Eutrophication/upwelling, harmful algal blooms	Better planning; farm siting; regular monitoring; emergency procedures
Increased virulence of pathogens, new diseases	Better management to reduce stress; biosecurity measures; monitoring; appropriate farm siting; improved treatments and management strategies; genetic improvement for higher resistance.
Acidification impact on shell formation	Adapt production and handling techniques; move production zones, species selection
Limits on fish and other meal and oil supplies/price	Fish meal/oil replacement; better feed management; genetic improvement for alternative feeds; shift away from carnivorous species; culture of bivalves and seaweeds

Impact area	Potential responses
Post-harvest, value addition	
Extreme event effects on infrastructure/ communities	Early warning systems and education; new or improved physical defences; accommodation to change; rehabilitation and disaster response
Reduced/ more variable yields, supply timing	Wider sourcing of products, change species, add value, reduce losses, costs; more flexible location strategies to access materials; improve communications and distribution systems; diversify livelihoods
Temperature, precipitation, other effects on processing	Better forecasting, information; change or improve processes and technologies
Trade and market shocks	Better information services; diversify markets and products

Source: adapted from Daw *et al.*, 2009; De Silva and Soto, 2009.
Note: Some adaptations to declining and variable yields may directly risk exacerbating overexploitation of fisheries by increasing fishing pressure or impacting habitats.

Decisions as to which options to select will depend on the location and scale of change; the impacts and the perception of their effects; and the cost, complexity and time required to implement countermeasures. Priorities may be given to small and inexpensive changes in systems or practices that can bring about additional risk reduction. However, if larger climate change risks emerge, these actions may quickly become redundant, or more dangerously, offer a false sense of security. In these circumstances, when time may be required to develop new techniques and/or gain access to investments required, a more strategic approach may be needed. However, early over-investment in expensive forms of protection may pose dangers in that they may deprive communities of important financial resources and protect only some sectors of the population. In some cases, tradeoffs may be required to support decisions to protect and strengthen one area, community or activity, while leaving others relatively unprotected. Over longer periods, infrastructure development and the relocation of people towards safer or more attractive areas may be required.

Tables 10.2, 10.3 and 10.4 extend these concepts to show how climate change responses may be developed in different fisheries, aquaculture and associated sectors, depending on the potential level of severity of change. The levels of disturbance are categorized as: minor disruptions, which are relatively easily to accommodate through normal patterns of operations, but may merit some adjustments to reduce risks and impacts; significant disruptions, which are sufficient in frequency and magnitude to require adjustments outside the normal patterns of operations, but usually only require modifications to these familiar patterns; and major disruptions whose frequency and/or magnitude expose the system to unsupportable levels of risk and for which it is imperative to make modifications, some but not all of which could be based on existing systems.

In the broader response to uncertain vectors of change, climate-smart disaster risk management approaches are also relevant. This approach originated in post-disaster interventions (e.g. storms, floods or tsunamis) where there was the need to reduce or manage similar risks. However, the approach can be applied much more proactively and can be used to anticipate and respond to the complete climate change impact profile in a given context. In this way, better links to response needs can be made in areas where storms are also associated with sea level surges and salinisation or the destruction of nursery habitats (read more about disaster risk reduction in Module 10).

Table 10.2
Climate change impacts and response options in specific fisheries systems

System	Significance of system	Climate disturbance level – example issues (I) and responses (R)		
		Minor*	Significant**	Major***
Inland/ coastal casual fishing, usually traps, lines, gathering	Major importance for subsistence food and secondary income; opportunistic in range of water bodies; approx 10% global output, 200 million people US$5billion or more	I - Changing species mix with differing tolerances, ecosystem disruptions, fishing conditions change; R - Adapt to catch different species, use different locations, timing, possible brood- stock/ nursery areas	I - More flood and drought impacts, increased die-offs, some weather risks possible reduced access by poorer groups, less household food R - more marketing of output, possible stocking/ restocking	I - Flood, drought, temperature and salinity impacts, losses of stocks in range of locations; R - fewer substitution options (species, location) for local beneficiaries, may need food security support measures
Inland/ coastal recreational fishing	Fishing for food and/ or leisure activity in many areas; strong economic multipliers in wealthier markets; approx 10% output, 200 million people, US$30billion	I - Changing species mix with differing tolerances, shifting locations; R - adapt to different practices, places, timing, adjust stocking/restocking, improve habitats, adjust management	I - Wider impacts; R - more use of stocking, habitat modification, protection of key stocks; political influence to regulate, invest in eco-system protection and/ or improvement, reserve areas, reduce take for food.	I - Wide range of impacts, losses of stocks in specific locations, changes of use of key water areas; R - greater development of designed/ managed fisheries, limited access to biodiversity reserves
Small-scale fishing with passive gear – traps, gill nets, longlines	Significant global sector; mainly coastal; major source of market and domestic supply; low capital and energy needs; around 15% global output, 40 million people, US$25 billion	I - Shift of species mix, timing, locations; R -adapt gear, timing, access/ develop alternative markets, possibly adjust management – e.g. size restrictions, close seasons	I - Larger disruptions to stocks, locations, timing; higher fishing risks; R - further adaptation/ development of gear, timing, access; possible advantages to those with greater research and development (R&D) options, more use of management controls	I - Further disruptions, higher fishing risks but low cost, ease of use of gear maintain its preferred usage; may become more significant in e.g. Low Impact and Fuel Efficient (LIFE) fishing; R - further adaptation, shifting markets, more management controls
Small-scale fishing with active gear – dredges, seines, trawls	Important globally; mainly coastal; range of fish, shellfish species, key source of higher-value market supply; higher capital and energy needs; around 10% global output, 15 million people, US$15 billion	I - Changing species mix, timing and locations; more effort required per catch; R - adapt gear, timing, adjust management, reduce energy costs by improving returns	I - More disruptions to stocks; higher risks, poor catches and high cost may make some fishing unviable; more management limits; R - possible move to passive fishing options or need to develop alternative livelihoods	I -Further disruptions and higher risks of non-viability of some systems; greater pressure on management, R - alternative fishing options, develop higher value markets, move to alternative livelihoods.
Commercial driftnet, long-line fishing	Key pelagic and other fisheries/species activity in some regions, commonly open seas, international scope; around 1% global output, 0.5 million people, US$ 1.5 billion	I - Changes in distribution across wider zonal areas, more effort per catch, time taken R - expand gear size; develop markets for bycatch	I - Greater disruptions and unpredictability; R - extend effort responses, improve stock monitoring/location options, move to higher values, improve bycatch options	I - Further disruptions, greater chance of non-viability; R - better targeting possibly smaller units, higher value and market quality;
Commercial dredge, trawl fishing	Important demersal and shellfish species activity in many regions, more localized; around 5% global output, 1 million people, US$ 7.5 billion	I - Changes in species, timing, location; more effort per catch, time taken; R - adjust or develop gear, practices; add value to product; develop markets for bycatch	I - Greater disruptions of stocks, timing, location; extend responses, R - improve stock monitoring/location options, move to higher values, improve bycatch options	I - Further disruptions, greater chance of non-viability; R - better targeting possibly smaller units, higher value and market quality;

System	Significance of system	Climate disturbance level – example issues (I) and responses (R)		
		Minor*	Significant**	Major***
Commercial purse-seine fishing	Important for major pelagic stocks in key regions, mainly marine, highly efficient if effectively targeted; around 10% global output, 0.1 million people, US$ 0.1 billion.	I - Changes in distribution across wider zonal areas, more time to locate catch, possible dispersal; more time and effort per catch, but efficiency still relatively good; R - increase stock protection	I - Further disruptions, stock unpredictability, dispersal problems; R - improve stock monitoring/location options, possibly move to higher market quality and values,	I - More extensive disrupt-ions, stock dispersal issues; R - increase stock monitoring/ location efficiency, move to higher value and market quality; greater chance of non-viability, capacity reduction;
Freezer/ trawler /factory vessel fishing	Linked to a number of commercial fishing types, may also take up small-scale fishing inputs, in many areas, around 1% global output, 0.1 million people, US$ 0.05 billion	I - Distribution and fishing activity changes; R - adjust operations for changing patterns of activity/catches, change trip length, landing locations	I - Wider disruptions of species/locations; R - more flexible operations, further develop processing/ product options; possible reduction in viability	I - Further disruptions for stocks and catch options, greater chance of non-viability; R - possibly aim for higher value and market quality; may need to decommission.

Notes:
* minor disruptions – relatively easily accommodated within normal pattern of operations, may merit some adjustments to reduce risks/impacts;
** significant disruptions – sufficient in occurrence/magnitude to require adjustments outside the normal pattern of operations, but usually only requiring modifications to these
*** major disruptions – occurrence and/or magnitude exposing the system to unsupportable levels of risk, imperative requirement for modifications, some but not all of which could be based on existing systems.

Table 10.3
Climate change impacts and response options in specific aquaculture systems

System	Significance of system	Climate disturbance level – example issues (I) and responses (R)		
		Minor*	Significant**	Major***
Seabed based mollusc culture, artisanal and commercial	Traditional in wide range of coastal areas, some mechanized, household consumption or markets; around 2% global output, 1 million people, US$ 1.5 billion	I -Small changes in productivity, spatfall, substrate quality, disease and predator interactions. R-adjust seeding locations (if done) and harvesting patterns, better health monitoring	I-Greater changes in productivity, substrate quality, ecosystems, etc, some stocks less viable R- adjust locations, manage substrates, adjust seed options (if used), change predator management, harvest patterns	I-Notable changes in productivity, greater damage risks, safety issues in some sites, stock viability changes R-adjust sites, practices, select better seed, improve value and returns, possibly shift to suspended culture systems
Commercial suspended mollusc culture	Expanded in coastal zones in many latitudes, commercial markets; around 3% global output, 0.5 million people, US$ 3 billion	I-Small changes in productivity, natural spatfall, more exposure risks, change in disease (inc red tides) and predator interactions R-slightly adjust locations, modify systems, adequate monitoring and early warning in place, management practices, harvest cycles	I-Greater ecosystem changes, extreme events, spatfall, disease and predator issues; higher risks, some sites less viable, others more so; R- Improve monitoring systems strengthen farming systems, adjust locations, management practices, ensure reliable hatchery seed production, harvesting	I- Much greater ecosystem changes, damage risks, safety issues, some areas become unviable R- Move to new areas needed for production, strengthened systems, better management approaches, reliable seed production from hatcheries, insurance; ensure alternative livelihoods and options

System	Significance of system	Climate disturbance level – example issues (I) and responses (R)		
		Minor*	Significant**	Major***
Extensive warm-water coastal pond/ lagoons	Traditionally unfed some fertilisation, wild or stocked fry, traps or nets; some molluscs, around 0.5% output, 0.2 million people, US$ 0.5 billion	I- Slight changes in productivity, species, temp ranges, possible runoff, fertility, some disruption to natural spawning, algal biomass R-change harvesting, greater inputs/stocking, management, possible expansion with sea level rise	I-More changes, less predict-ability, runoff, salinity changes, possible anoxia, fish kills; other areas less productive; some damage risks R-change harvesting, where feasible greater management, stocking, small cages, other inputs, water exchange	I-Greater ecosystem disruptions, flood and storm damage potential, productivity risk, species changes R-change harvesting, if feasible greater physical protection, intensified management, small cages and other subsystems, water exchange
Partially fed inland/coastal pond systems	Mainly inland, intensified with increased stocks and yields; range of practices and species mixes, water exchange, aeration; around 15% output, 1 million people, US$ 25 billion	I-Slight changes in temp ranges, salinity, water exchange, productivity, species performance, disease risks; R- adjust stocking/ feeding/harvest strategies, more water management / backup systems, monitor system/health more closely,	I- More water quality changes, less stability, possible anoxia fishkills, disease and productivity loss, some damage risks; R- change stock/feed/ harvest strategies, more physical protection, water management, possible reuse; possibly intensify stocking, management, monitor environmental conditions and early warning systems	I-More ecosystem disrupt-ions, flood and storm damage potential, productivity risk; R-if feasible to continue, increase physical protection, Improved monitoring and early warning systems, intensify water management, production, shorten production cycles, change species mix
Integrated farm units	Usually inland ponds/ paddies, with plants, animals; range of options; around 0.5% output, 0.2 million people, US$ 0.5 billion	I- Slight seasonal/ ecosystem changes, marginal shifts in productivity, disease risks in some/all components; R-adjust integration mix, possibly increase use; improve management	I-Greater changes, temperature and water balance, greater instability potential; R-possible new aquatic/ other species mixes, timing, consider wider options for adapting other systems, monitor environmental conditions and early warning systems	I-Larger disruptions, flood and drought risks, R-possible relocation/ reorganization, develop new components and markets, reduce crop cycle times, Improved monitoring and early warning systems,
Completely fed inland/ coastal pond systems	Gradually intensified or purpose planned; highly stocked fish, shrimp, water exchange, aeration, treatment; around 3% output, 0.5 million people, US$ 5 billion	I - Temperature, salinity and other water quality instabilities, disease risks; R - better system management, backup systems, adjust species, possibly intensify and/ or reduce crop cycles, monitor environmental conditions and early warning systems	I - More challenging instabilities, greater infrastructure risks; R - modify structures, higher levels of feed and water management, possible water reuse, link with integrated systems, monitor environmental conditions and early warning systems	I - Greater risks of physical and ecological disruptions, R - possible redesign/ reconstruction/relocations; possible expansion in salinised land areas, improved monitoring and early warning systems,
Intensive tank and raceway systems	Highly intensified, controlled, high water exchange, mainly hatcheries and high value fish, inland and coastal; around 0.05% output, 0.02 million people, US$ 0.01 billion	I-Localised management issues of temperature and water supply R- modify production cycles, feed regimes, more water treatment; better health and hygiene management, possible species/strain adjustments	I-Possibly greater challenges of water supply and quality; R-greater water(full recycle) and feed management, shifts in species/strains and timing of production cycles; less use for ongrowing, mainly hatcheries and nurseries	I-Much greater potential disruptions/supply/quality risks; R-possible shifts in species/ seasonal cycles, Full water recycle; flow-through ongrowing less common.

System	Significance of system	Climate disturbance level – example issues (I) and responses (R)		
		Minor*	Significant**	Major***
Intensive cage systems	Widespread globally inland and coastal, mainly fish, intensive fully fed, wide range of systems, species; around 5% output, 0.5 million people, US$ 10 billion	I-Temperature, salinity, oxygen level changes, possible algal blooms, pathogen interactions, marginally increased risks R-better stock, feed and disease management, proper (risk based) site selection, some relocations; monitor environmental conditions and early warning systems	I- Greater range of ecosystem variability, higher risks; also storm damage, losses. R- closer monitoring, local/ system-wide early warning; change species/strains, short-cycle production, more relocations	I - Wider range of disruptive effects, some areas too risky unless very short-cycle, high value crops; R - possible new areas in lower-risk zones with system wide risk reductions; improved monitoring and early warning systems,
IMTA systems	Coastal, linking intensive fish cages/ ponds with molluscs and marine plants at range of scales; <0.05% output, 0.01 million people, US$ 0.001 billion	I-Temperature, salinity, oxygen level changes, marginally increased risks R-Some adjustments to balance components, timing and outputs, ensure interacting component physically secure, avoid negative environmental feedbacks	I- Greater range of ecosystem variability, higher risks; also storm damage, losses. R-Further adjustments to component mixes, cycle times, more robust physical systems, possible relocations in some areas; also possible scope for expansion as risk-reduction strategy.	I- Increased disruptive effects R-More targeted integrated design and component choice across a range of systems to manage range of risk and ensure resilience. Could be expanded further if these can be better developed.
Recycle aquaculture systems	Fresh or salt water, tanks or ponds with substantial water treatment/reuse; mainly hatcheries or high value species; 0.05% output, 0.01 million people, US$ 0.3 billion	I-Relatively small risks associated with intake water supplies, power and infrastructure security R- may require system/ operating adjustments. Some open systems may use more recycle to stabilize water quality and supply.	I-Increased risks related water supply, power and infrastructure R-More open systems may turn into higher water reuse. Higher external variability may require greater system control, backup provision, high recycle rates. Tradeoffs with energy costs likely to become more important.	I- High risks related water supply, power and infrastructure R-Maximum recycle rates to maximize independence from external environment. External factors such as site, infrastructure security more important, possible relocations to purpose designed systems.

Table 10.4
Climate change impacts and response options in specific post harvest/production systems

System	Significance of system	Climate disturbance level – example issues (I) and responses (R)		
		Minor*	Significant**	Major***
Small landing facilities	Inland or coastal, various small structures, some with shelter, water, ice, fish handling areas, cool or cold storage, some with vessel/ gear repair/store; handling some 30% of global output	I - Possible access disruptions, risk of physical damage, breakdown of facilities, higher costs of protection, maintenance or repair; some may become non-viable if more distant from fishing areas. R - options to select and concentrate landings need to be investigated.	I - More significant disruptions with greater consequences; greater possibility of dislocation from fishing areas, higher costs and lower local value retention. R - Investment in facility upgrades would require effective climate-proofing.	I - Potentially major dislocations from resource areas, greater physical risks increasing potential for non-viable operations R - may need specific investments in climate-proofed facilities and infrastructure networks.
Commercial port/handling unit	Larger, more developed, higher specification facilities for landing, marketing, distribution, normally in cold chain, with defined standards; services for vessels/ gear etc; some 70% global output.	I - Risks of resource access/higher costs of supply, balanced by continued potential to add value, protect investment, maintain supply chain expectations; risks of physical damage and quality disruptions. R - Aquaculture may gain in importance.	I - Greater risks of disruptions, non-viability, particularly from reduced throughput in multiple-sourced centres; R - possible greater aquaculture role; some relocations, or more flexible systems/ operations; costs of improving infrastructure may need to be recovered	I - More extreme impacts of resource dislocation, physical risks, R - potential shifts to vessel-based handling and processing, landing to less specialized centres. New, lower-risk centres may also develop, and numbers of risks may reduce.
Fresh product supply systems	Range of inter-connected storage, handling, transport elements linking first sale to markets, retail outlets; around 30% global supply	I - Resource access changes R - some relocations, adjustments, potentially added costs. Impacts of shifts to aquaculture.	I - Greater disruptions to supply and quality, R - reorganization of elements, more aquaculture material, some systems may be less viable, more processing needed to protect quality.	I - Further extension of disruptions, R - need for relocation, re-organization, changing product streams, markets, process options. More investment and competition impacts.
Small-scale drying/smoking activities	Primarily linked with artisanal fishing, simple racks, kilns, packaging, local transport; around 10% of global supply	I - Resource access issues, also water, fuel wood other inputs R - some shifts in location, markets, improved systems/operating procedures.	I - Greater impacts in similar issues/themes R - greater potential for change in locations, supply chains, impacts on producers and communities.	I - Further extension of risks and disruptions, greater livelihood impacts; R - options for improving markets, adding value, improving prices, more significant.
Commercial processing systems	Wide range of facilities operating to defined health/ hygiene standards meeting market needs; range of secondary products; around 30% supply	I - Resource access and quality changes R - some relocations, adjustments, potential added costs, possible shifts to aquaculture.	I - More disruption to supply and quality, more aquaculture material, some systems may be less viable R - need to develop wider range of products, byproducts, other options.	I - Further disruptions, R - need for relocation, reorganization, changing product streams, markets, process options. More investment and greater competition impacts.
Prepared food manufacturing and distribution	Specialist food centres using/adding value to aquatic products, linking by range of transport to highly co-ordinated distribution systems	I - Resource access/quality changes; impacts of other raw material R - some relocations, adjustment, potential added costs, possible shifts to aquaculture, changes in product forms	I - More disruption to supply/ quality, more aquaculture material, some units may be less viable; R - need to develop wider range of products, adjust aquatic food content; new markets.	I - Further disruptions R - possible need for relocation, reorganization, changing process options, product streams, markets. More investment and greater competition impacts.

Building resilience

By targeting specific areas of vulnerability, the resilience of households, communities and nations can be increased. However, if these areas of vulnerability are addressed only selectively or partially, remaining vulnerabilities may jeopardize or even negate any positive effects. Moreover, in many areas, unresolved issues outside the fisheries and aquaculture sector may limit the potential for building resilience. In this regard, there are several key principles on which to base analysis and action, including:

- Systems with more diversity tend to have greater resilience.
- Initiatives to build resilience can connect across scales. Actions to build resilience at the local-level can reinforce each other to create greater resilience on a broader scale. National resilience, which can be improved, for example, through market and economic strategies, can create a more positive environment for building local resilience.
- Perspectives for resilience need to acknowledge all the elements in the impact pathway for development. Where possible, tradeoffs between the risk to resilience and costs of building resilience should be identified.
- Climate change-induced drivers can be important, but they may not be the only factors that need to be addressed. In some circumstances, they may be relatively insignificant.

Theme 3: Reducing and removing GHGs

As for the terrestrial food systems, fisheries and aquaculture GHG emissions, mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are associated with various aspects of production and distribution; while management of the aquatic ecosystem itself has important potential for reducing net GHG flux to the atmosphere through the natural sequestration of carbon. There are also possible options for aquatic biofuel production, which could be linked with the fisheries and aquaculture sector. In addition, there may be interactions with GHG mitigation efforts in the energy sector in areas such as hydropower and coastal and offshore renewable energy generation. Three areas of interaction can be articulated: the sector's own contribution to GHGs and the potential for reducing these emissions; the sector's potential role in supporting the natural system's removal of emissions; and the sector's role in providing alternative energy sources.

The role of the sector in reducing its emissions

Although there are still substantial areas that need to be addressed, information on GHG emissions and their potential reductions from aquatic food production and distribution systems is becoming more clearly understood (Poseidon, 2011; Muir, 2012). For capture fisheries emissions are primarily related to fuel use. The nature and levels of emissions depend not only on technical aspects, such as types of vessels and gear used (e.g. active/passive gear, trawl, dredge, seine, gillnet, longline, light-attraction fishing, traps) (Muir, 2013) but also on driving market forces and management of fishing capacity – too many vessels chasing after fewer and fewer fish tends to increase fuel use. Emissions of particulate 'black' carbon could add significantly to current estimates, but this issue needs further investigation. For aquaculture, feed is considered to be the primary determining factor for emission levels and fertilizers are a secondary factor. Therefore, GHG emissions tend to increase as an aquaculture system moves from being extensive (untreated or partially fertilised), to semi-intensive (fertilised and/or partially fed) to intensive (completely fed and fertilized). Fuel and energy use for water exchange and treatment, service vessels and vehicles, and husbandry equipment also add to CO_2 emissions, but is usually much less significant. The relatively undetermined effects of CH_4 in sediments and N_2O in sediments and the water column are also potentially important and need to be further defined.

Processing fish and aquatic animals ranges from simple artisanal drying and smoking to highly controlled seafood preparation using high-specification packaging and labelling. In this regard, energy use is the primary determining factor for GHG output. There are wide variations in emissions depending on local practices, input variations (species, sourcing, quantity and quality) and operating efficiency. Water used in food processing and its links to GHG emissions may also be important. As the most widely traded global food product, aquatic foods may travel considerable distances in a range of forms and in various states of perishability. In this regard, GHG outputs are usually directly related to fuel use and to energy use in handling and cold and freezer storage. The specific choice of refrigerants is also important. Leakage from old or poorly maintained equipment can be critical, as many low ozone depletion gases have significant global warming potential. The most perishable fresh products require transport methods (e.g. local trucks, live fish vessels and air transport) that emit higher levels of GHG. Cooled and frozen products require less time-critical transport methods (e.g. ship-borne reefer and freezer containers) that emit fewer GHGs. More stable products (dried, smoked and salted products), particularly those processed in artisanal supply chains, require methods for transport that are not time-sensitive and produce low levels of GHGs.

Overall, the ratios of GHG output per tonne of fish and aquatic foods at the production, distribution and retail stages are similar to those for other foods. GHG levels at first sale accounts for typically 25-40 percent of total outputs. However, these figures vary widely. Limited numbers of comparative assessments of CO_2 equivalents per kilo across the different food production systems suggest that high fuel-use fisheries (e.g. poorly catching trawl or dredge fisheries) together with high-energy use post-harvest systems can be among the most GHG-intensive global food systems. Passive fishing gear systems or low-trophic level aquaculture (e.g. bivalves, seaweeds) can produce foods at lower GHG levels than most forms of meat or related animal protein production.[4] Such systems have the potential to contribute to strategic shifts in consumption and to reductions in global GHG emissions.

The role of the sector in supporting the natural removal of emissions

The highly significant role of the oceans and coastal margins in capturing and sequestering carbon is becoming increasingly understood and recognized. Around 93 percent of global carbon is estimated to be stored in aquatic systems and around 30 percent of annual emissions are estimated to be sequestrated in aquatic environments, primarily in mangroves, seagrasses, floodplain forests and coastal sediments (Nellemann *et al.*, 2008). To improve the sector's role in removing emissions, it is of primary importance to halt the disruption of carbon sequestration caused by habitat destruction and inadequate management of fisheries and aquaculture. Secondly, there may be valuable prospects for enhancing sequestration through expanding planted areas of mangroves and floodplain forests. Development of carbon funds to support GHG sequestration in the aquatic systems needs to ensure fisheries and aquaculture communities are properly represented and able to benefit from such funds.

There is also wider potential for exploring the role of aquaculture in carbon sequestration. Primary options include integrated multitrophic aquaculture (IMTA), where molluscs and seaweeds are grown as byproducts using waste inputs from more intensive aquaculture and systems where aquaculture cage or pond sediments are managed to enhance sequestration. These offer potentially valuable means of storing carbon. However, removing the carbon in longer-term conditions would require more secure means of disposal. This would involve either a biochar-type system or the disposal of carbon-enriched materials below oceanic thermoclines and into deep sediments. The physical and economic practicalities of this are yet to be demonstrated.

The role of the sector in providing alternative energy sources

There are major technical and environmental interests in developing the potential of renewable aquatic energy. This includes aquatic substrate biofuels and creating links to other aquatic-based energy systems that exploit the energy potential of tides, currents, waves, wind and hydropower. There are also options for physical integration of aquatic-based energy systems with newly developing infrastructure such as offshore wind and wave installations. Currently, there is particular interest in algal biofuels, which are based on either microalgae that are typically cultivated in coastal ponds or intensive stirred tank systems or macroalgae (seaweeds) that is grown in conventional culture systems. Using microbial enzymes to produce fuels such as bioethanols and biodiesels is an already established practice, which is increasing in efficiency and yield. This is particularly the case with genetically engineered (GE) bacterial enzyme systems capable of digesting celluloses and in some cases providing direct conversion to biofuel. GE algae are also a possibility, but they would require more expensive containment and biosecurity systems. The costs of producing and harvesting algal raw materials are currently too high to make production viable for any of the proposed systems and fuel routes. However as oil prices rise and production efficiencies improve, this procedure may become more viable. It should be noted that, as is the case for terrestrial biofuels, algal biofuels will provide an emission displacement function only and they will not lead to a net sequestration of carbon (more discussion on energy questions in Module 5 on energy).

[4] See De Silva and Soto, 2009 for a comparative description of energy use in aquaculture systems.

Box 10.7
Improving small-scale operators' incomes through the introduction of fuelwood saving fish processing technology in a FAO programme in Liberia

Baseline information has shown that post-harvest operations in small-scale fisheries in Liberia are characterized by mishandling and poor fish processing methods. This was the case in Grand Kru and Montserrado, two fishing centres that participated in the Food Security through the Commercialization of Agriculture(FSCA) project. The poor quality products, especially the smoked products, are less competitive and fetch lower prices. Even when wood was available for smoking, prices for wood had risen significantly. For those who could not afford to buy wood, it has become necessary to walk much further to gather wood for fish-smoking operations.

In Grand Cess, an important fishing centre on the Western southern coast of Liberia in Grand Kru County, the proximity of the lucrative border market with Cote D'Ivoire represents a business opportunity. However, the operators who wanted to tap into this market faced significant challenges as they had to compete with better quality products from other fishing villages.

Traditional oven uses more fire wood.

Women use their fuel-efficient oven to produce good quality fish products

The FSCA project started its work in Grand Cess in 2009. The project developed post-harvest fish technology platforms, constructing Chorkor fish smoking ovens and insulated containers for fresh fish storage. In total, 241 operators benefited from the project, out of which 179 worked in Grand Kru. The Good Father Fishery Based Organization (GFFBO) was a successful example of an organization that benefited from project support. This Fishery Based Organization (FBO) has 38 members: 11 men and 27 women. The Chorkor oven is well-known for its fuel efficiency performance, reducing by two-thirds the ratio of wood used to fish produced compared with traditional ovens. It also produces less smoke and produces good quality products. In Grand Kru, the Chorkor oven introduced by FSCA is now being widely used as the best means of fish preservation. This technical intervention, combined with the development of organizational and entrepreneurial skills, has increased the self-esteem of beneficiaries. They now feel confident in selling their goods at cross-border markets. In 2011, a report presented at the FAO-organized expert meeting in fish technology, safety and quality assurance, highlighted the socio-economic improvements that have been achieved through this assistance. With improved incomes from increased sales and better management, the GFFBO initiated some initiatives to boost self-reliance. It procured a canoe, a 25 horse power outboard engine and an assortment of fishing gear and met all other variable costs during one operational year. This FBO then embarked on a plan to construct decent houses for members, which is in line with their expressed objectives for improved sustainable livelihoods. With training sessions, practical experience and the outcomes achieved during the project period, members are now waiting to open personal accounts with local banking institutions as soon as banks are opened in Grand Kru.

Box 10.8
LIFE fishing - gaining benefits by reducing footprints?

- Low Impact and Fuel Efficient (LIFE) fishing refers to fishing gears and practices that ensure that fish are caught using the minimal possible amount of fuel with minimal impact on the environment.
- The global fishing fleet is estimated to consume some 41 million tonnes of fuel per year at a cost of US$ 33 billion at an average price of US$ 800 per tonne.
- Between 2002 and 2008 the price of oil rose from US$ 20 per barrel to over US$ 130, severely affecting the profitability of the catching sector. Though prices have since fallen, they remain substantially higher, continue to be volatile and pose further threats to the sector.
- Each type of fishing gear and practice has advantages and disadvantages in terms of fishing selection, supply and energy efficiency.
- The suitability of each gear largely depends on fishing area and species, and optimal solutions vary among fisheries.
- Success of transition to LIFE fishing will heavily depend on:
- developing acceptable technology for vessels, gear and operating systems;
- creating appropriate incentives for change;
- avoiding rigid regulatory regimes that can discourage fishers from innovating and adopting new technologies;
- developing close cooperation between the fishing industry, managers, scientists and other stakeholders to develop and introduce cost-effective and practical LIFE-fishing technologies; and
- using global research and development to support the development and uptake of LIFE fishing.

Source: Suuronen *et al.*, 2012

10.4 Strategic climate-smart approaches for the sector

The previous section has described the three main thematic areas of climate-smart approaches for fisheries and aquaculture. To create an effective framework for response, these thematic areas need to be addressed at a range of strategic scales and levels. The following practical and operational options can be considered, grouped according to their different entry points and scales. At this stage, the list of options is not exhaustive. They will be developed and detailed further as experience is gained and as best practices become more clearly established.

National and regional level approaches

- Build the capacity for developing strategic national and supranational perspectives on combined mitigation and adaptation (including disaster risk reduction and management) approaches for the fisheries and aquaculture sector. Link this work with sectoral and other development programmes, funding mechanisms (including climate change and GHG options). Define the most critical approaches, timelines for mobilization and indicators of outcome.
- Develop clearer perspectives on the tradeoffs between costs and policy related to energy and the profitability, output, competitiveness and trade of the fisheries and aquaculture sector. Explore and define links between food security and the sector.
- Develop practical perspectives on national and regional aquatic food supply potentials under climate change scenarios to inform economic and trade strategies. This would address the following questions: Are adaptation costs too high for production and profits to be ensured? Is it strategically more effective to increase imports or invest in production elsewhere? If supply potential is increased (e.g. movement of stocks, growth conditions for aquaculture, other locational advantages) what and how much investment is required to benefit from this, and what might be the trade and value-added opportunities?
- Carry out strategic institutional and human capital analyses and development. Identify potential sources of data and information. Gain a better understanding of decision-making at various levels. Develop awareness, preparedness and skills. Improve political interactions. Develop risk-related financial instruments with market and product perspectives to increase supply and demand flexibility, and broaden sector supply resilience.

Strategic industry and subsector levels

- Assess and define strategic investments (e.g. infrastructure for protection and enhancement of production and supply chain components). Define tradeoffs between 'hard' and 'soft' engineering strategies (e.g. classic infrastructure, such as roads, harbours, power, market and processing facilities and the service sector) and macro-level aquaculture protection, water supply and drainage systems, versus adaptation actions with minimal infrastructure costs.
- Define and develop landscape-level interactions with other sectors that address hydrological planning, coastal protection works, and their links with aquatic habitats. Define and establish rules, tools and models for achieving this integration in ways that cover bioecological, physicochemical and sociopolitical issues. Develop 'smart' geo-engineering approaches for building resilience and enabling productive transformation.
- Provide strategic opportunities for newer forms of integration, such as managed aquatic systems and habitats that are linked with renewable energy and other forms of energy development.
- Undertake subsector initiatives to identify and promote best practices, resilient supply strategies, and focused R&D to reduce risk.

Local and enterprise levels

- Define the local social, economic and policy context (e.g. economic dependence, livelihood options, human, social and financial capital, institutional context and capacity building options).
- Use capital and operating cost models to explore implications of different scenarios (e.g. incidence and levels of flooding, rainfall and water exchange, temperature, salinity, aquatic system features, such as algal blooms, and disease transmission on aquaculture production). Generate viability profiles under different scenarios, and where relevant, develop locationally based (e.g. geographic information system [GIS]) risk maps for key aspects.
- Identify practical aspects of risk reduction, including physical modifications (e.g. physical structures and storm and flood protection), changing operating strategies, environmental management, diversified and segmented supply chains, cross-investments, diversified species mixes, input options and markets. Link old knowledge to new options and build capacities.
- Where necessary, define and specify relocation options, policy and investment opportunities, livelihood alternatives and opportunities for diversification.

Individual and community levels

- Identify stakeholders and their roles and dependences, key risks and options, and their connections to current and emerging development objectives.
- Define and develop local learning processes and exchanges of information that can be validated with clear performance indicators.
- Develop and use information and communication technology for specific exchanges of ideas, information and options. Where possible, establish relationships with other communities to permit comparisons and the development of good practices.
- Support effective participation in cross-sectoral negotiations and planning processes.
- Develop external partnerships to provide specific technical and social support investment and resilience building.

Box 10.9
Impacts on and the role of trade in supporting climate change adaptation in the fisheries and aquaculture sector

The overall implications of climate change for fisheries trade are not well known. However, climate change will increase uncertainties in the supply of fish from the sector. Climate-induced changes in natural resources used for fishing and aquaculture will require fishing communities, producers, processors, fish traders and exporters to adapt. Changes in total fish catch, the composition of the catch, and the distribution of fish resulting from climate change could affect global import and export patterns. Moreover, fisheries export revenues could be affected as well as the contribution of fisheries sector exports to total exports. Likewise, the potential occurrence of sea level rise and greater frequency of extreme events will have an impact on ports and other physical infrastructure that support trade fisheries operations. These events are likely to add to the costs of fishing and could affect the competitiveness of exports.

Trade policy can play an important role in reducing vulnerability. Appropriately designed trade policies and rules can contribute to eliminating economic distortions, such as harmful subsidies, which encourage overcapacity and overfishing. Such reforms would also enhance the supply-side capacities and competitiveness of sustainably managed fisheries. Reforms that discourage economically unviable fishery operations can stimulate economic diversification. Trade policies can equally be important in supporting adaptive capacities.

Trade-related assistance and climate change financing mechanisms could be used in a complementary and reinforcing manner, as parts of efforts to render developing countries' fisheries sector and economies more resilient to climate impacts and other external shocks. For example, assistance to strengthen trade-related infrastructure could enhance both the trade-related supply-side capacities and the climate change adaptation needs of developing countries. Key complementary policies should also effectively promote the diversification of production and exports; foster the production of higher value-added processed goods; and develop the supply-side capacities of small-scale and artisanal fisheries and other vulnerable actors within the sector.

Developing countries should continue to argue for the elimination of distorting fisheries subsidies and the reduction of tariff escalation and other barriers to trade. This may promote more efficient use of fisheries resources and enhance market access for their fisheries products and increase their development opportunities. Moreover, they should maintain enough policy space that could allow them to adopt measures to restructure their economies. This will be instrumental to make developing countries' fisheries and their economies at large more resilient to climate change and other external shocks.

In addition, some measures being proposed to address climate change may have negative trade implications for developing countries. Initiatives to reduce carbon emissions and mitigate climate change, like the 'food miles' campaign, for instance, may negatively impact developing countries' fish exports, given their distance from import markets. Food miles refer to the distance food travels from its production until it reaches the consumer. However, the concept only centres on one part of the carbon footprint, namely transport, ignoring other parts of the production process. But if the entire supply chain is considered, fisheries exporters operating in developing countries may produce goods with a lower carbon footprint. Finally, eco-labelling could provide new market opportunities and increase the value added to fishery and aquaculture products.

Combined with efforts to reduce overcapacity and overfishing, trade and trade policies could be instrumental to foster resilience to climate change in developing countries. Appropriately designed trade rules can discourage economically unviable and environmentally damaging fishing, provide support mechanisms to preserve supply-side capacity in developing countries and create policy space in support of adaptation to climate change in developing countries.

Below are some essential steps for supporting the role of trade in climate change adaptation in fisheries and aquaculture:

- Eliminate non-tariff barriers to fish trade that distort world supply and demand.
- Eliminate tariff escalation for high-value fisheries imports that distort world supply and demand.
- Encourage domestic and regional trade in fish and fisheries products to reduce the carbon imprint of fish trade.
- Support research on the impacts of climate change and climate change policies on trade in fish products.
- Develop options for product and export diversification through appropriate economic and trade policies.
- Market and label goods produced following recognized energy efficient standards (e.g. eco-labelling)

Source: ICTSD, 2009

10.5 Progress of fisheries and aquaculture towards CSA

At this stage, the definition and validation of CSA approaches for fisheries and aquaculture are in early processes of development and dissemination. Consequently, there is little experience as yet that can be used as a widely tested foundation for good practices. However, a number of underlying principles can be identified and applied, both to define concepts and to measure progress towards meeting agreed aims. To define progress in meeting CSA criteria, it will be important to select and use practical indicators that address the common needs of relevance, accuracy, accessibility and cost-effectiveness. Measures of 'pressure-state-response' as developed for sustainability indicators may be useful. These measures would establish connections between the nature and extent of climate change drivers, the state of the impacted system, and the response generated and applied through the CSA approach.

It will also be useful to apply generic indicators for CSA that cover such areas as the demonstrated continuation or expansion of output and quality, resource accessibility, food security, human nutrition and health, together with direct or indirect measures of GHG impacts. At the subsectoral level, various measures of resource use and impact efficiency such as fuel, energy, land or water use per unit of output, and GHG emissions per unit of output will also be applicable. A number of more sector-specific indicators may also be relevant. These may be used to varying extents in composite indicators, for example in cases where there may be social or environmental tradeoffs with more conventional production-defined indicators. These indicators would include criteria such as aquatic biodiversity, ecosystem status, gender equity and social dependence indices. Based on a defined range of such indicators, normative scenario building will be helpful for specifying the current conditions of the sector and the desired status over a specified period (assessments, monitoring and evaluation are discussed in Module 12).

Clearer definitions will also be required for the status and function of primary resources and their use in the fisheries and aquaculture sector. This will serve to determine the current status of the sector, trends, potential acidification and climate change impacts and how changes in the efficiency of resource use are delivering social and economic benefits.

10.6 Transitioning to CSA

The current characteristics and vulnerabilities of the aquaculture and fisheries sector to acidification, climate variability and change can be identified. However, it is less easy to define the broad priority areas for action based on the potential impacts and adaptive capacity of different systems and the specific pathways and mechanisms for moving towards more robust and resilient systems. Nonetheless, based to some extent on equivalent issues in other food production and natural resource sectors, a number of points can be noted:

- It will be critical to build capacity and improve performance in basic aquatic resource management to ensure underlying resilience in the face of uncertainty.
- Incentives will be the key to CSA transitioning through social, legal, institutional, or economic and market-based incentives. Ideally, financial or other benefits will make CSA self-sustaining so that it will only require an additional impetus during the transition period. This impetus could be provided through access to improved fisheries and aquaculture techniques and materials, institutional change and strengthening, capacity building and the development of participatory monitoring systems.
- Some elements necessary for the transition to CSA will require longer-term strategic investments in infrastructure, productive capacity, and improved products and services, including aquaculture stocks and feeds. This will be necessary to meet emerging needs and avoid losses. The case for these investments, and the rate at which these investments need to be deployed, will need to be assessed and tools for doing so will need to be refined.
- Smaller-scale changes and response can be carried out locally with current resources and knowledge. These changes can be extended relatively simply by supporting the sharing of knowledge and experience and through additional institutional strengthening.

- Fisheries and aquaculture are embedded within complex ecosystems, for which it will be very difficult to predict responses to climate change. Adaptive and low-cost monitoring systems to help define potential consequences and test responses will be necessary. These systems will need to be interactive and capable of building a strong and well shared knowledge base across user groups.
- Markets and trade may help buffer changes in production that have an impact on food security, consumer prices and supply-demand gaps. However, implications of climate change impacts and climate change policies through the supply and value chain need to be better understood. Appropriate policy measures need to be defined and implemented.
- Public and private sector investment and collaboration will be needed to meet future demands and ensure the sector meets CSA objectives and delivers longer-term benefits. Including multiple stakeholders in CSA planning will foster creative options for action and help to minimize unintended consequences of chosen options.
- Many of the components of CSA can be strategically matched with broader development objectives, such as sustainability, social equity and biodiversity. These different goals need to be effectively integrated.
- Improved basic fisheries and aquaculture management, including the reduction of overcapacity and over-fishing, are key to building the resilience of fisheries and aquaculture socio-ecological systems as well as supporting the sector's GHG mitigation efforts.

10.7 Conclusions

The issues and practical approaches outlined in this module provide the framework within which the fisheries and aquaculture sector can define and apply climate-smart processes and actions. This will reduce the impacts of climate change, improve the sector's mitigation potential and increase the resilience of producers, supply chains and communities. It should be noted that optimizing all variables of CSA at the same time is not likely to be a realistic option and may not even be necessary. Prioritizing actions will depend on the context and objectives for the fisheries and aquaculture sector in a given area and on the production system as a whole.

Developing rapid and effective responses to climate change in the fisheries and aquaculture sector, and mainstreaming climate-responsive approaches within wider development goals represents a significant strategic and operational challenge. Conventional approaches for building and validating evidence within traditional disciplines and contexts may not always be feasible. Experience will need to be built up through an adaptive management process based on action learning with broad participation and information sharing among stakeholders. In addition, the nature of climate change vulnerability will need to be further explored. Practical means need to be developed to ensure that the most vulnerable states, production systems, communities and people have the potential to develop and apply sound CSA approaches.

Case study 10.1
Catfish farming in Viet Nam – the challenges of change

The farming of catfish (Pangasianodon hypophthalmus), also known as tra, sutchi, Pangasius, and striped catfish in the Mekong Delta of Viet Nam is hailed as a global success in aquaculture production. The sector currently produces over 1.2 million tonnes in a pond acreage of less than 6 000 ha. It employs over 170 000 people, and in 2009 generated an export income of over 1.4 billion US$. This success has triggered the development of subsidiary sectors for feed production, food processing and waste recycling. It is important to note that this boom in production has occurred within a short period of a decade or less. During this period, traditional backyard farming has been transformed into a highly vibrant commercial activity, with over 97 percent of the final product destined for export to over 100 nations and territories (De Silva & Phuong, 2011). Catfish production has provided an acceptable alternative 'white fish' in the global market place (Duc, 2010; Little *et al.*, 2012).

An increasingly efficient farming system with a comparatively lower carbon footprint

The catfish farming sector is the highest yielding primary production sector. The global average is 250 to 400 tonnes per ha/crop. Details on the estimated protein and fish meal usage in the sector are given in the following table. It indicates that only 146 600 tonnes of fish meal and no fish oil is used in the sector.

Total Production	1,200,000 t	De Silva and Phuong, 2011
Average FCR (feed conversion rate)	1.45	Phan *et al.*, 2009
Total feed used	1,740,00 t	
Average protein content in feed	26-30%	
Total protein used for production	487,200 t	
Estimated fish meal used in production	146,160 t	If 30% of protein derived from fish meal

From 2005 to 2010, the processing sector improved significantly. About 1 kilogram (kg) of processed product was derived from 1.69 kg of fresh fish and overall 'waste' was reduced. This waste is not put in landfills and other forms of disposal, but is converted into fish oil and meal. The meal is used as animal feed. At least three of the country's biggest processing plants are involved in this activity.

The sector has attracted much criticism from environmentalists who claim that there is an excessive usage of feeds and effluent discharge. However, this criticism has not been backed by explicit scientific evidence. On the contrary, Little *et al.*, (2012) shows that from a comparative perspective, catfish farming in Viet Nam has a comparatively low environmental impact. It has also been demonstrated that the overall emissions from tra catfish farming contributed less than 1 percent of total suspended solids, nitrogen and phosphorous in the Mekong Delta as whole. For a sector that produces over a million tonnes of food and generates a revenue in excess of US$ 1 billion, this level of discharge is miniscule (De Silva and Phuong, 2011).

The mean water consumption was of farm volume of 6.4 ± 0.8 megalitre per tonne (megaL /t) and a discharge of 3.4 megaL/t. This level of water consumption is much lower than in shrimp farming in ponds, which ranges from 11-43 megaL/t) and the tank culture of salmonids, which is 252 megaL/t (Beveridge *et al.* 1991). Phan *et al.*, (2009) estimated the total water consumed in 2007 was that 4,371 gigaL of water (based on 683 000 tonnes of catfish production in the whole of the Mekong delta). Out of this total, 2 754 gigaL was discharged back to the river. The amount of water used for the production of a tonne of catfish was 4 023 m3, or 4 m3 per kg. Other estimates for water use in pond culture are around 40 m3 per kilo (catfish farming in North America). The reduction in the case of catfish is due to the intensification of production. It is interesting to note that water lost through evapotranspiration in rice cultivation is estimated to be around 1.7 m3 per kg of rice, but productivity of rice is 4.5 tonnes per ha and with an export of 115 kilograms of nitrogen per hectare.

The water and nutrients lost through drainage from aquaculture ponds can be used to irrigate or fertilize crops, either on the dike or in adjacent fields (Prein, 2002). In stagnant systems, such as ponds that are extensively fed or aerated, drainage is irregular and limited at maximum to a few days per year. This makes the use of drainage water from such systems impractical for crop production, unless the drainage water can be stored in a deep reservoir for later use (Mires, 2000). Nevertheless, small-scale farmers often consider their pond primarily as a reservoir, from which daily water is drawn for crop or animal production and household use (Luu, 1999). By integrating water storage and aquaculture, the water needs for aquaculture is shared with other on-farm activities, which greatly reduces water use directly related to aquaculture.

The resilience of this sector has been tested mostly by market forces. As mentioned above, the sector has also faced criticism about its purported negative environmental impact. This criticism, which has been widely disseminated though the internet, has so far been shown to have no scientific basis. Nevertheless, the sector continues to thrive. It provides a classic example of the effective recycling of waste and has a relatively low carbon emission scenario compared to most primary production sectors.

The Mekong River has the eighth highest discharge of all major rivers in the world. Catfish farming is done in the lower reaches of the delta, which has plentiful water resources. This enables the sector to operate effectively and reap high yields. However, further expansion of the farming area and greater intensification of production may not be possible. A further reduction of the discharge levels to the Mekong River will be the key to the sector's sustainability.

Is catfish farming in Viet Nam well adapted to climate change?

This very productive aquaculture system may not be well prepared to face climate change. Rising sea levels are a real threat in the lower Mekong. The catfish farms may be exposed to increased salinity in the mid and long term. In the short term, catfish farming may be sensitive to some climate change variability and trends. For example, increasing temperatures and changes in the hydrological patterns may trigger disease outbreaks. A tight biosecurity framework is currently not in place, and given the high density of farms and very high density of fish production, a disease outbreak could devastate the sector.

Catfish farming can become more climate-smart through better planning of farm locations, improved water and nutrient management, and enhanced integration with other farming systems. However, a more urgent measure is a tighter biosecurity framework. Catfish farming can also become more climate-smart by implementing an EAA that would ensure the participation of all stakeholders and improve their understanding of climate change-related risks and prevention measures. For example, increasing salinity could be addressed by moving farms upstream, although this is an unlikely scenario. A more long-term approach to adaptation would to develop catfish varieties that are more resistant to salinity.

Case study 10.2
Integrated multitrophic aquaculture as a means of improving resilience

Integrated aquaculture systems share the management of resources, such as water and feeds with other farming systems. Usually, a new aquaculture species is integrated into an agricultural or agro-industrial system. Outputs from one subsystem, which otherwise may have been wasted, become an input to another subsystem. This leads to greater efficiency in the use of outputs produced from the land and water resources that are under a farmer's control. Integrated aquaculture has been widely practiced by small households, mainly in Asia, as a low-cost and efficient food production system in freshwater environments. In recent years, the idea of integrated aquaculture has been often considered as a mitigation approach against excess nutrients and organic matter generated by intensive aquaculture activities. This has led to the emergence of integrated multitrophic aquaculture (IMTA). Multitrophic refers to the explicit incorporation of species from different trophic positions or nutritional levels in the same system (Chopin and Robinson, 2004).

Two-season farming model of integrated shrimp culture with Manila clam and rabbit fish in Southeast China
This farming system produces two seasons or cycles annually, and is mainly used by shrimp farmers in Fujian and eastern Guangdong provinces of China. Shrimp (Penaeus monodon in Spring, Marsupenaeus japonicas in Autumn), Manila clams (Ruditapes philippinarum) and rabbit fish (Siganus fuscescens) are farmed together in the same pond. The pond size typically ranges from 0.5 to 3 ha, with muddy-sandy sediment and marine water depth of 1.0-1.5 m. Two aerators (1.5 Kw) are equipped per ha. Only the shrimps are artificially fed with commercial shrimp feed or trash fish. The Manila clam and rabbit fish eat the byproducts inside the pond (Shao, 2007; Weng, 2006; Feng *et al.*, 2009).

Inputs and yield of the system (according to Shao, 2007; Weng, 2006; and personal survey in 2011)

Table 1.
Seasonal seeding of the farming model

Season	Species	Seeding amount (/ha)	Size
Autumn (August)	Ruditapes philippinarum	2.6 tonne	1180-1290 ind/Kg
	Marsupenaeus japonicus	0.3×106 individuals	0.8~1.0 cm
	Siganus fuscescens	15×103 individuals	400 ind/Kg
Spring (March)	Ruditapes philippinarum	1.9 tonne	400-460 ind/Kg
	Penaeus monodon	0.4×106 individuals	0.7-0.9 cm
	Siganus fuscescens	15×103 individuals	400 ind/Kg

Table 2.
Annual production* and potential for increasing yield

Species	Average annual yield (t/ha) in monoculture	Estimated yield in the integrated farming system (t/ha)
Marsupenaeus japonicus	1.8	2.4 - 3.0 by intensive feeding and disease control
Penaeus monodon	2.2	2.8 - 3.5 by intensive feeding and disease control
Ruditapes philippinarum	14.2	14.6 - 16.0
Siganus fuscescens	1.1	1.4 - 1.8
Penaeus monodon	0.4×106 individuals	0.7-0.9 cm
Siganus fuscescens	15×103 individuals	400 ind/Kg

* The shrimp production in Table 2 represents the average yield in monoculture model for these two species in Southeast China. This figure could be lower because the possibility for disease outbreaks is much higher than it is for IMTA. However, the production level of L. vannamei is much higher (average 6-8 tonne/ha) but not included in the current IMTA model.

Carbon footprint and energy use Carbon input (ton/ha)	Carbon output / harvest (tonne/ha)	Carbon balance (tonne/ha)	Energy use (KW*H)
Seeding 0.18 Feeds 0.70	Shrimp & fish 0.35 Manila Clam 0.57	-0.04	900 - 1200

Carbon content of fresh Manila clam: 4 percent (Lu *et al.*, 2005); carbon content in shrimp feed: 10 percent; carbon content in shrimp and fish: 6.8 percent. Energy use according to Shao, 2007. 2005.dile lowing.3.

Ecosystem services

Manila clam filter feeds on phytoplankton and organic detritus. Rabbit fish feed on macroalgae. Because of these feeding habits the system acts as a carbon sink of 0.04 t/ha. The average electricity use of the farm is about 1 200 kilowatt hour (kWh). This is equal to about 0.2 tonnes of carbon. Electricity use is much lower than in normal semi-intensive monoculture of shrimp. There are nearly no organic pollutants and nutrients discharged. To make this IMTA system carbon neutral, the shrimp stocking intensity could be reduced in favour of increased stocks of bivalve shellfish and integrated with macroalgae culture. However, current levels of shrimp stocking are determined by the profits that can be earned, which is the strongest factor for determining the composition of farming systems.

The system employed 0.5 -1 person per ha during routine farm management. But more than 20 persons per ha are employed during the calm harvest. These figures only take into account direct employment. Indirect employment can be an order of higher magnitude.

Species	Yield (t/ha)	Price(US$/kg)	Annual value (10^3US$/ha)
Marsupenaeus japonicus	1.8	12.7 - 16	26
Penaeus monodon	2.2	4.4 - 8.0	14
Ruditapes philippinarum	14.2	1.0 - 1.2	13.5
Siganus fuscescens	1.1	2.5 - 4.0	3.5
Sum	19.3	-	≈57

Case study 10.3
Mussel farming: a food system with minimal GHG emissions

Cultured filter feeders (e.g. bivalves, such as mussels and oysters, and some echinoderms, such as sea cucumbers) and algae do not need external feeds. They can live on carbon and other nutrients in the environment. Mussel farming can be done with no or minimal GHG emissions and low or minimum environmental impacts. The impacts of mussel farming are most often related to the production of feces or pseudofeces, which when they accumulate in sediments can cause Hypoxia (lack of oxygen). However, well planned, well situated and appropriately sized shellfish culture seems to have little effect on the community of organisms which live on, in, or near the seabed (benthos), even when large areas are occupied. On the other hand, the benefits of biological absorption of nutrients for control of eutrophication[5] symptoms have been documented in many parts of the world. It is clear that the existence of significant filter feeder aquaculture (e.g. in China) has been instrumental in controlling coastal eutrophication, probably on a national scale (Ferreira *et al.*, 2013).

In countries such as China, mussel farming provides an important source of food and protein and supports associate livelihoods. In countries with lower seafood consumption, such as Chile, mussel farming provides jobs and livelihoods and a large proportion of the production is exported. In general, the ecosystem services of extracting nutrients and reducing eutrophication risks in the water column have not been properly evaluated. However, Bunting and Pretty (2007) build the case for the culture of mussels (Mytilus edulis) on rafts in Killary Harbour, Ireland, (as described by Rodhouse and Roden, 1987). They estimate that 10.8 tonnes of carbon per year would be assimilated[6] in mussel production and that the removal rate of carbon during harvest was 0.008 tonnes of carbon m-2 per year 1, which is equivalent to 80 tonnes of carbon per ha per year.

The great majority of mussel farming is carried out in floating or underwater holding systems that facilitate the mussels' permanent filtration of phytoplankton from the water. These systems use two types of techniques: suspended lines from a floating tray or individual long lines tied to a weight on the bottom; and a floating system on the surface. Mussel seeds attach to these lines and individuals grow by feeding on the available phytoplankton. Most bivalve farming can be carbon-friendly and is comparatively energy efficient. However, these farming systems are sensitive to several threats related to climate variability and climate change. The most common climate-related threats include changes in water quality (e.g. temperature and salinity) and increased frequency and prevalence of red tides.

Mussel farming in Galicia and in Southern Chile

Mytilus galloprovincialis is the main species of mussel farmed in the Galicia Rias in Spain. Mussel growth is very fast. Normally is takes about 18 months for mussels to reach commercial size, but in many cases, mussels can grow to commercial size in one year. The Ria Arousa is the most productive area for mussel farming. It benefits from an upwelling system, that regularly contributes cold water and nutrients, which causes exceptional phytoplankton production that can sustain more than 2 000 floating rafts. The rafts or floating platforms are a rectangular wood frame of about 500 m2. Usually one raft is one farm and is owned by a single family. Estimated annual yield for the Ria Arousa is about 60 tonnes per ha without shell. The annual estimated production for Galicia is around 250 000 tonnes (with shell). Current preliminary estimates of employment indicate that about 10 000 people live directly or indirectly from the mussel farming in Galicia.

In Chile, the most common farmed species is *Mytilus chilensis.* Farms can be of different size and operate at different scales of production. The farming is done using long lines. A 'mother line' normally about 100 m in length is held by floats and tied to the bottom. Many vertical lines hang from the mother line. Farming density can range from 10 to 12 long lines per ha in protected bays, channels or fjords in a water column that can reach from 10 to 40 m in depth. Estimated yield ranges from 60 and 70 tonnes per ha without shell. In 2011, Chile produced 221 000 tonnes of mussels. Although there is no current available quantitative information, it is claimed that mussel farming activities generate significant local direct and indirect employment not only through farming but also in the processing, an economic activity that employs mostly women.

[5] A condition of excessive algae production due to excessive nutrient availability, which usually leads to a situation of hypoxia and losses of biodiversity.

[6] Mussels feed on particles and assimilate carbon.

Mussel farming sensitivity to climate change and adaptation potential

Mussel farming in both southern Chile and Galicia is very sensitive to red tides, which have been increasingly associated to climate change and climatic variability. The best approach for reducing exposure to red tides is the implementation of permanent food safety monitoring programmes. These programmes lower health risks and improve preparedness. In both countries, aquaculture systems have such programmes in place. Since mussel farming tends to be carried out in more protected coves and bays where higher phytoplankton productivity can be ensured, it is generally less exposed to weather events than other aquaculture systems. Nevertheless, these farming systems are sensitive to extreme weather events. Ocean acidification can be a major climate change threat for all bivalve farming as lower levels of pH in the water can interfere with the formation of the calcium rich valves and other physiological processes in the mussels. Adaptation to such a threat may involve activities such as selecting resistant strains of mussels and increasing hatchery-produced larvae under more controlled conditions. Another potential threat is the lack of available wild seeds. The production of wild seed can be strongly affected by coastal oceanographic conditions and nutrient availability. In this area climate variability and climate change play key roles. Again the production of larvae in hatcheries and adequate management of the broodstock are essential adaptation measures.

Notes

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Acronyms

ABNJ	areas beyond national jurisdiction
CBF	culture-based fisheries
CH_4	methane
CO_2	carbon dioxide
CSA	climate-smart agriculture
DRM	disaster risk management
EAA	ecosystem approach to aquaculture
EAF	ecosystem approach to fisheries
EEZ	exclusive economic zone
ENSO	El Niño Southern Oscillation
FCR	feed conversion rate
FBO	Fishery Based Organization
FSCA	Food Security through the Commercialization of Agriculture
GE	genetically engineered
GFFBO	Good Father Fishery Based Organization
GHG	greenhouse gas
GIS	geographic information system
ICTSD	International Centre for Trade and Sustainable Development
IMTA	integrated multi-trophic aquaculture
IPCC	Intergovernmental Panel on Climate Change
IUU	Illegal, unreported and unregulated
kg	kilogram
kg N/ha	kilograms of nitrogen per hectare
kWh	kilowatt hour
LDC	Least Developed Country
LIFE	Low Impact and Fuel Efficient
megaL /t	megalitres per tonne
NH_3	ammonia
N_2O	nitrous oxide
NO x	nitrogen oxides
PIC	Pacific Island Countries
PNA	Parties to the Nauru Agreement
PO_4	phosphate
R&D	research and development
SO_2	sulphur dioxide
VDS	vessel day scheme

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