B4 Climate-smart fisheries and aquaculture

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Overview

The fisheries and aquaculture sector is likely to experience some of the greatest impacts on productivity and livelihoods as a result of climate change and climate variability and their influence on the distribution of resources (chapter B4 – 3). The impacts of climate change and adaptation options vary by region. Local context-specific, climate-smart agriculture solutions will be required to guide the sector toward a sustainable future. Chapter B4 – 4 explores how the objectives of climate-smart agriculture can be reached in the fisheries and aquaculture sector, and describes the ecosystem approach to fisheries and aquaculture, which establishes a framework to holistically address climate change across marine and coastal systems. Chapter B4 – 5 provides a summary of strategic climate-smart approaches for the sector. Chapter B4 – 6 outlines the progress of the sector in making the shift to climate-smart agriculture, the priority areas of action for the future and areas where further research is needed.

Key messages

- The 1995 Code of Conduct for Responsible Fisheries (FAO, 1995) and the ecosystem approach to fisheries and aquaculture (FAO, 2003) outline the principles and approaches that are central to ensuring the sustainability of the sector. Their relevance has never been greater given the need for effective management to respond to climate change and climate variability.
- There is a growing understanding of the broad implications of climate change and climate variability on aquatic resources. However, information on local impacts and vulnerabilities is lacking, which hampers adaptation planning at the community and national level. Increased research at the national level and improved capacities for decision-making under uncertainty are needed.
- A range of actions will be required to make fisheries and aquaculture climate-smart: improving efficiency in

the use of natural resources to produce fish and other aquatic foods; overcoming constraints to accessing markets and, in particular, establishing new regulations to prevent fish caught through illegal, unreported and unregulated (IUU) fishing from entering supply chains; maintaining the resilience of aquatic systems and the communities that rely on them to allow the sector to continue contributing to sustainable development; and gaining an understanding of how to reduce the vulnerability of those most likely to be the hardest hit by climate change.
- Examples of win-win approaches for attaining climate-smart agriculture objectives include: the improved management of unsustainable fisheries through effective management of capture fishery capacity, and the application of fishing measures that address the underlying drivers of overfishing, such as subsidies that develop overcapacity of global fishing fleets; increased productivity through better integration within production systems and within broader landscapes and seascapes; improved feeding by reducing waste and improving Fish In - Fish Out (FIFO) ratios; reduced losses from disease in aquaculture, especially where rising temperatures adversely affect farmed species; the reduction of pre-harvest and post-harvest losses; and the further development of regional trade and the building of resilience along the whole value chain.
- Activities to manage fisheries and aquaculture operations to achieve the goals of climate-smart agriculture must be undertaken at all levels (individual, business, community, national and regional) and time scales. Representatives of stakeholders from the private, civil and public sectors will need to be involved in the development of context-specific options.
- Managing fisheries and aquaculture operations so that they achieve the goals of climate-smart agriculture will also require targeted assistance to ensure that the most vulnerable states, production systems, communities and stakeholders have the potential to develop and apply climate-smart approaches.
- Markets and trade may help buffer the impact of changes in production. This is especially true for the most vulnerable Small Island Developing States (SIDS) and coastal communities along the equator. Rising temperatures, which causes shifts in the distribution of ocean resources, will ultimately affect food security. Consumer prices and supply-demand gaps need to be addressed in light of the potential climate-induced changes in productivity and availability. Finally, the implications of the impact of climate change and climate change policies on the entire supply and value chain need to be better understood.

Introduction

Scope

The scope of this module covers climate-smart agriculture from the fisheries and aquaculture perspective. This module has been developed to provide policy-makers and other stakeholders with information on options and priorities for promoting the development of productive, climate-resilient, and low-carbon capture fisheries and aquaculture. It provides the latest knowledge on the impacts of climate change, opportunites for adaptation and incresed productivity and potential mitigation options. Experiences from various contexts are considered: Lake Tanganyika, Viet Nam's Mekong Delta, Southeast China, Chile and Spain. The impacts of climate change and adaptation options vary by region. Local context-specific, climate-smart agriculture solutions will be required to guide the sector toward a sustainable future.

Objective

The fisheries and aquaculture sector is likely to experience some of the greatest impacts on productivity and livelihoods as a result of climate change and climate variability and their influence on the distribution of resources. In this sector, climate-smart agriculture focuses on adaptation strategies (examples of good practices are given in the Annex) and the necessary steps in governance to prepare the most vulnerable populations, especially in SIDS and coastal communities, for the potential changes. Through seaweed farming and improved coastal management (e.g. the protection and management of mangrove forests and estuaries), the sector can also remove carbon from the atmosphere. This module highlights the potential for climate-smart agriculture practices in fisheries and

aquaculture sector to contribute to mitigation. Healthy ecosystems are the foundation of climate change adaptation and mitigation. The module describes the ecosystem approach to fisheries and aquaculture, which establishes a framework to holistically address climate change across marine and coastal systems, as well as inland fisheries and aquaculture. Finally, the module provides guidance on conserving fuel in the global fishing fleet by reducing overcapacity, and examines the carbon imprint of the growing trade in fish and fisheries products, which are the most highly traded food commodity.

Fisheries, aquaculture and climate change

This module addresses the following questions: What are the implications of climate change and climate variability for the sector? How can resilience be built and vulnerability be reduced within the communities that depend on fisheries and aquaculture? What does the sector need to do to reduce its greenhouse gas emissions, provide alternative sources of energy and support natural greenhouse gas sequestration and carbon storage services?

B4 - 3.1 Climate change processes and impacts

The Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPPC) provides evidence of the certainty of global warming and its effects on oceans, coastal areas and inland waterbodies (FAO, 2016a). Climate change, along with other phenomena that affect climate variability, such as El Niño-Southern Oscillation, and extreme weather events, are affecting the abundance and distribution of fisheries resources and the suitability of some geographical locations for aquaculture systems. Climate-related physical and chemical changes are linked to increasing carbon dioxide emissions. These emissions are being absorbed in large part by aquatic systems, which is triggering substantial changes in aquatic ecosystems and affecting the important services they provide for maintaining food security and livelihoods (FAO, 2016b).

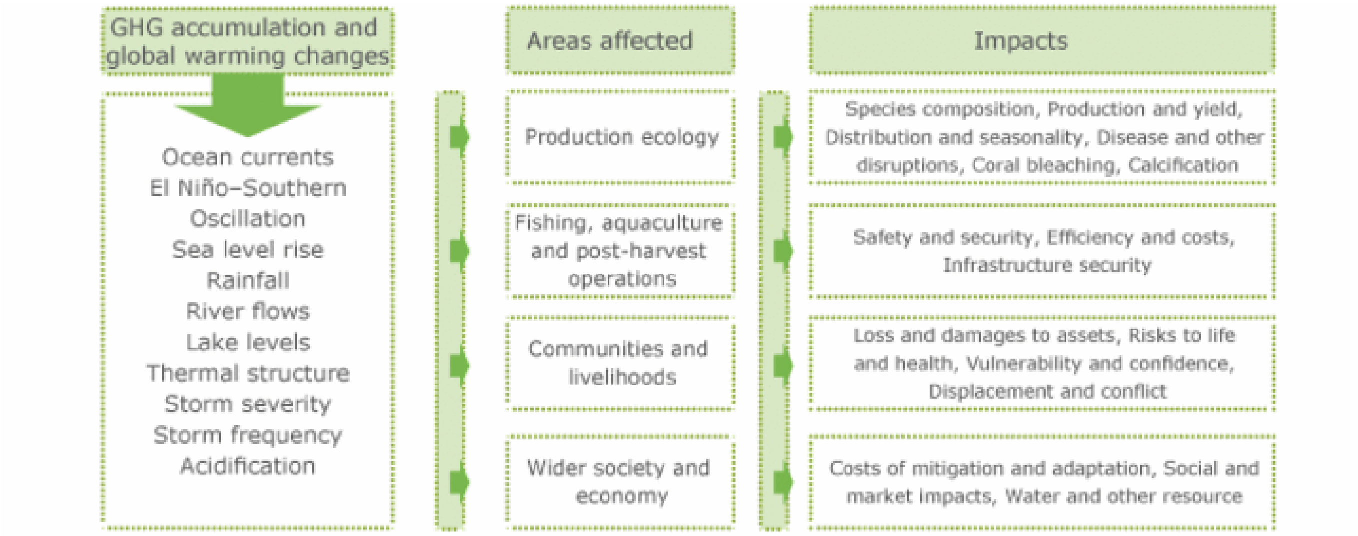
Climate-related changes that affect ecological functions and the frequency, intensity and location of extreme weather events include: changes in salinity and freshwater content; oxygen concentration; carbon uptake and acidification; temperature and thermal stratification; sea levels; ocean circulation; surface wind, storm systems and waves (Cochrane *et al*., 2009; FAO, 2016b). These changes can be expected to have a range of impacts, both direct and indirect, on fisheries and aquaculture. These impacts are outlined in Figure B4.1. Scientific knowledge on the impact of individual climatic drivers varies, and information on is limited the combined effects of these drivers is limited. This uncertainty complicates adaptation planning within the sector. Human drivers, such as pollution, dam construction and unsustainable fishing, are exacerbating the harmful impacts of climate change (FAO, 2016b).

Evidence exists that climate change is modifying the distribution of marine species. Many species are migrating towards the poles and deeper waters to follow their ideal habitat conditions (e.g. oxygen levels) (Figure B4.2). These migratory shifts cause changes in interaction dynamics among species, trophic linkages and food webs. Where migration is not possible, many aquatic species are likely to undergo changes in their size, reproductive cycles and survival rates. The impacts, both positive and negative, will depend on the region and latitude. Certain commercial species are likely to move offshore and away from traditional fishing grounds, with new invasive species likely moving in to fill the vacuum. If these new species are fit for human or animal consumption, new livelihood opportunities may arise in some communities.

Despite the encroachment of species that are tolerant of higher temperatures and changes in the chemical content of coastal waters, ecosystem productivity is likely to be reduced in most tropical and subtropical marine environments, seas and lakes. Projected scenarios indicate increased productivity of capture fisheries in high-latitude systems, but decreased productivity in low- and mid-latitude systems (Figure B4.2). Coastal systems are particularly vulnerable to temperature increases, hypoxic zones, acidification, and extreme weather events (FAO,

2016b).

Figure B4.1. Example potential climate change impact pathways for fisheries and aquaculture



Source: developed from Badjeck et al., 2010.

Rising sea levels can displace brackish[i] and freshwater[ii] systems in delta zones and wipe out a range of agricultural practices. The destruction of coastal wetlands also has an impact on the productivity of freshwater fisheries and aquaculture. However, rising sea levels may also create new environments and new opportunities for the sector (e.g. through marine aquaculture and the expansion of mangrove forests). Increased frequency and intensity of storms, coastal flooding, coastal erosion and saltwater intrusion due to sea level rise could directly endanger fishers and fishing-dependent communities on coasts and at sea, and damage housing, community facilities and infrastructure used for fisheries and aquaculture. Marine shellfish aquaculture systems are especially vulnerable to changes in carbon chemistry, which can affect shell development in some species. For most species, the sensitivity to acidification and pathogens becomes greater when they are forced into habitats at the edges of their thermal ranges (FAO, 2016b).

The impacts of climate change on freshwater fisheries and aquaculture are expected to be significant. The increased variability in levels of precipitation and changes in air and water temperatures will affect the productivity of rivers, lakes and floodplains. Climatic drivers (e.g. higher temperatures) affecting inland ecosystems and species distribution are often intensified by non-climatic drivers, such as invasive species, pollution and habitat modification, and the fragmentation of rivers by dams. At the regional level, freshwater reservoirs will also be increasingly under pressure to meet the growing demand for irrigation. In general, inland fisheries will be at risk in areas where water stress is acute and the competition for water resources is high (FAO, 2016b). Case study B.4 provides an overview on how climatic and non-climatic drivers can contribute to changing the production potential of capture fisheries in aquatic inland systems.

Aquaculture systems will be affected by climate change through "gradual warming, ocean acidification, and changes in the frequency, intensity and location of extreme events" (IPPC, 2014a). Some production systems will need to be relocated (IPPC, 2014a).

For the fisheries and aquaculture sector, climate change may have significant impacts on post-harvest activities, the processes that add value to production and the distribution of fish to local and national markets. There may be potential changes in the location and variability of supplies, and changes in access to other key inputs, such as energy and water for processing. All these climate-induced changes will occur at the same time as other global, regional and national socio-economic pressures are being brought to bear on natural resources. This will expand the impacts on food security and nutrition, habitation and social stability.

Figure B4.2. Climate change effects on the distribution, body size and catch potential of marine fish and invertebrates

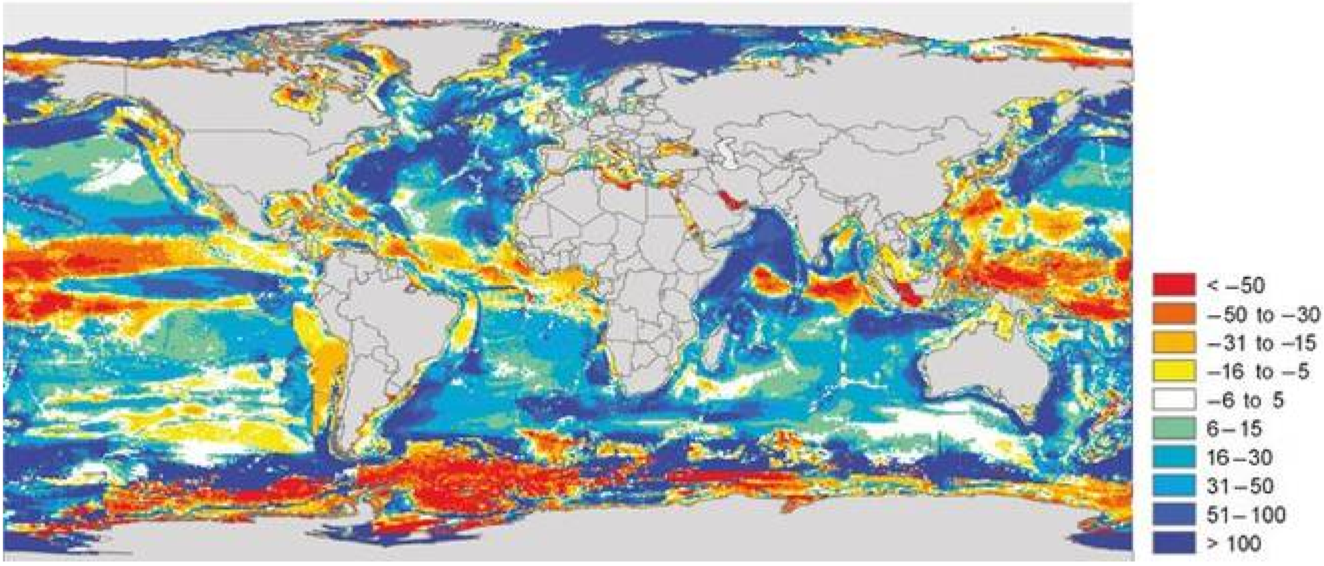


Figure B4.2 – Source: IPCC_AR5_WGII (A), chapter 6, p. 458. This graphic illustrates (a) Shifts in distribution range and reduction in body size of exploited fish driven by projected warming, oxygen depletion, and sea ice retreat. Whenever the shift in distribution does not fully compensate for warming and hypoxia, the result will be a decrease in body size. Shifts in (b) latitudinal and (c) depth distribution of 610 exploited demersal fishes are projected to have a median (central line of the box) of 31 km per decade and 3.3 m per decade, respectively, with variation between species (box boundary: 25th and 75th percentiles) from 1991–2010 to 2041–2060 under the SRES A2 (between RCP6.0 and 8.5) scenario (Cheung *et al*., 2011, 2013b). (d) Combining species' range shifts with projected changes in net primary production leads to a projected global redistribution of maximum catch potential. (Analysis includes approximately 1000 species of exploited fishes and invertebrates, under warming by 2°C according to SRES A1B (≈RCP6.0), comparing the 10-year averages 2001–2010 and 2051–2060; redrawn from Cheung *et a*l., 2010). (e) Changes in species distribution and individual growth are projected to lead to reduced maximum body size of fish communities at a certain site. The analysis includes 610 species of marine fishes, from 1991–2010 to 2041–2060 under SRES A2 (approximately RCP6.0 to 8.5; Cheung *et al*., 2013b), without analysis of potential impacts of overfishing or ocean acidification. Key assumptions of the projections are that current distribution ranges reflect the preferences and tolerances of species for temperature and other environmental conditions and that these preferences and tolerances do not change over time. Catch potential is determined by species range and net primary production. Growth and maximum body size of fishes are a function of temperature and ambient oxygen level.

B4 - 3.2 The growing demand for fish and other aquatic products

Oceans and inland waters can provide significant benefits to the world's population, especially in the world's poorest communities (The fisheries and aquaculture sector provides millions of people with food, income and livelihoods. According to recent estimates, 56.6 million people work in the primary sectors of capture fisheries and aquaculture (FAO, 2016b). If those who work in post-harvest activities of both subsectors are included in the figures, an estimated 660 to 820 million people, about 10 - 12 percent of the world's population, derive their income and livelihoods from the sector (FAO, 2012). Ninety percent of those working in capture fisheries are engaged in small-scale operations.

In 2014, the global population was 7.3 billion and it is expected to reach 9-10 billion by 2050. Population growth, but "more importantly the combination of urbanization, increased levels of development, living standards and income are key drivers of increased demand for fish and of fisheries development" (HLPE, 2014). With increased demand for fish and seafood, fisheries resources and production systems will grow in importance. Along with population growth, rising incomes, especially in developing countries, will create higher household demand for fish and seafood, as consumption of these foods tends to rise as the spending power of middle income consumers increases. This situation does not apply to the poorest of the poor, who fish at a subsistence level.

Population growth is increasing the demand for food, but unsustainable fishing practices have caused production from marine fisheries to level off. Aquaculture will have to satisfy the gap between capture fisheries, which produces approximately 93 million tonnes of food per year, and the projected growth in utilization, which is estimated to reach 261 million tonnes by 2030 (FAO and World Bank, 2015). To meet this demand, the aquaculture sector needs to increase production by 70-100 percent above current levels over the next two decades. There are several ways this could be done, for example, through innovations in feed conversion ratios, improved disease control, the intensification of production at existing sites and the development of new sites in underutilized areas. However, aquaculture development also faces growing constraints as competition for land, water, energy and feed resources intensifies. These constraints, combined with potential impacts of ocean acidification and climate change on ecosystems and dependent communities, present significant challenges to the entire sector (Brander, 2007; Béné *et al*., 2016; Little *et al*., 2016). Reducing waste and discards, strengthening the management of capture fisheries, increasing access to harvest and improving the distribution of fish and seafood products are also crucial for meeting the growing demand for fisheries and aquaculture products.

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.

B4 - 3.3 People, communities and vulnerability

When is climate change a risk?

To improve the understanding of how to support the adaptation process of natural and human systems to climate-related changes, the IPCC has modified its theoretical risk framework in its Fifth Assessment Report by recognizing that “climate change is not a risk per se” (IPPC, 2014a, p. 1050). Climate change only becomes a risk in systems that are unable to cope with it. Risk is explicitly linked to 1) the likelihood of climate-related events or change (e.g. sea level rise, acidification, increased water temperatures); 2) the degree to which the system is exposed to the hazard (e.g. the number of coastal communities in a region where the climate event occurs, the number of commercially important fish species in a lake, the existence of coral reefs); and 3) the vulnerabilities within the system (e.g. the lack of an early warning system, overfished resources, undiversified practices and livelihood strategies).

Who is at risk and where?

Hundreds of millions of people who depend on fisheries, aquaculture and fish processing for their livelihoods, food security and nutrition are at risk from the impacts of climate change (FAO, 2016a). Fishers, coastal communities and sector-related infrastructure are particularly threatened by extreme events (e.g. storms and cyclones) and sea level rise.

The IPPC's Fifth Assessment Report noted that one model projects that the annual landed value of marine fish in West Africa is estimated to decline by 21 percent, resulting in a nearly 50 percent decline in fisheries-related employment, and a total annual loss of US$ 311 million to the region’s economy relative to 2012 (IPCC, 2014b, p. 1221). A number of other studies have examined the potential impacts of climate change on fisheries and aquaculture. Allison *et al*. (2009) looked at the vulnerability of national economies by examining the impacts of climate change on their fisheries (see Box B4.1). Bell *et al*. (2011) considered the vulnerability of species, food webs and ecosystems, and explored issues related to tunas, feeding patterns, 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 measurements relating to the vulnerability

of the fishing communities that depend on the coral reefs as a way of capturing the links between the human activities and aquatic systems. Barange *et al*. (2014), by combining dependence of economies and food systems on fisheries with projected impacts of climate change, suggest that these impacts will be of greatest concern in South and Southeast Asia, South West Africa, Peru and some SIDS in the tropics. A good overview on the vulnerability of national economies to the impacts of climate change through fisheries is provided in Box B4.1.

In the Lower Mekong Delta in Asia, Cambodia and Viet Nam are among the countries that are most vulnerable to the impacts of climate change on fisheries (IPCC, 2014b, p. 1355). The Fifth Assessment Report identified Colombia and Peru as the South American countries whose fisheries are the most vulnerable to the impacts of climate change impacts. Their vulnerability is due to the combined effects of observed and projected warming trends; shifts in species and productivity in oceanic upwelling systems; the relative importance of fisheries to national economies and diets; and the limited capacity to adapt to associated risks and opportunities (IPCC, 2014b, p, 1526). Countries that have borders on semi-enclosed seas and/or depend heavily on their inland fisheries are likely to experience adverse impacts of climate change.

Coastal countries and communities, and those with major rivers and lakes, are particularly vulnerable to extreme climate events. An assessment conducted by FAO between 2003 and 2013 concluded that, in developing countries, the agriculture sector, including fisheries and aquaculture, absorbs approximately 22 percent of the economic damage caused by medium- and large-scale natural disasters (FAO, 2015a). SIDS, whose economies are highly dependent on fisheries and where the sector plays an important role in food security and employment, tend to suffer more from the effects of climate change and climate variability (FAO, 2015a).

Supply and value chains are likely to be effected by changes in temperature and humidity. For example, traditional food processing in the Arctic (e.g. the drying of fish) is at risk due to increasingly wet conditions (IPCC, 2014b p. 1583). Evidence of rising rates of food-borne illnesses, such as ciguatera fish poisoning, are heightening concerns about the impact of climate change on food safety (IPCC, 2014b, p. 1624). Along with its impacts on food security and safety, climate change may also threaten human health by increasing the incidence of other types of diseases. The impacts are likely to affect infrastructure in all sectors, as well as social services, causing displacement of communities and subsequent migration and/or conflict.

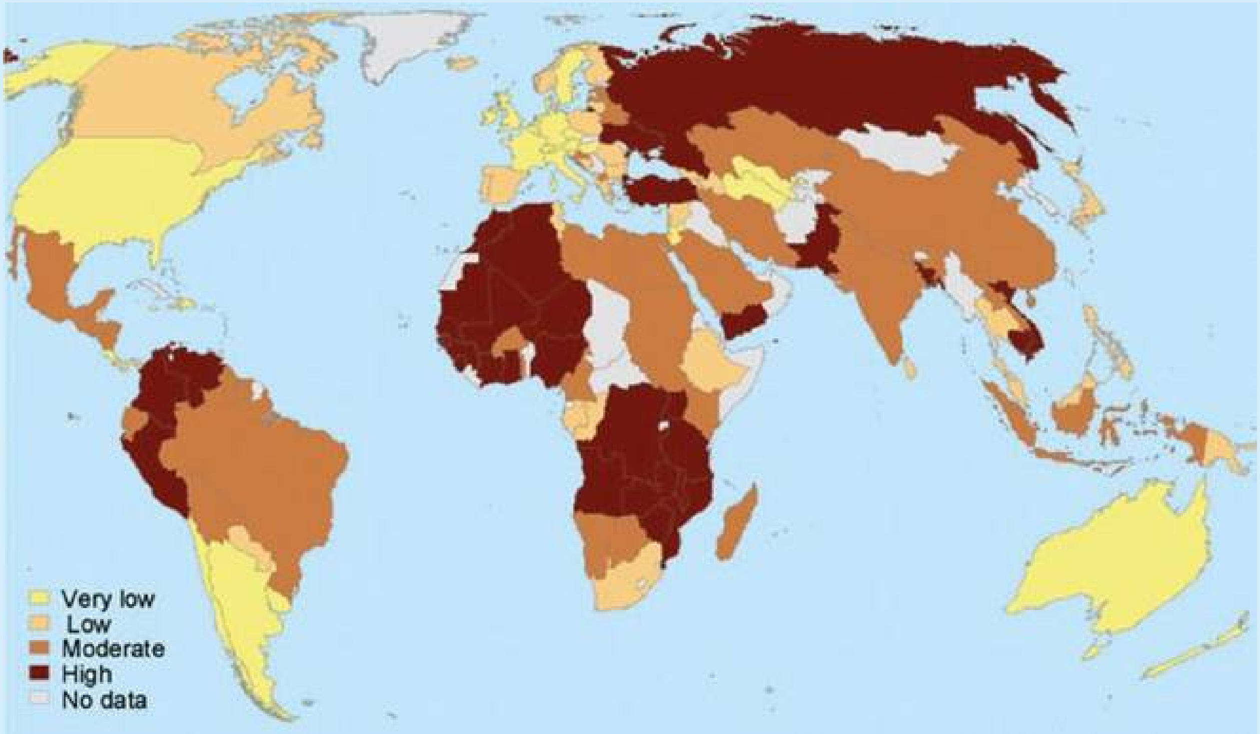
Countries that rely the most on fishery resources tend to be most likely to suffer the consequences of climate change (Barange *et al*., 2014). Small-scale fishers, who are heavily dependent on coastal and inland fisheries, are particularly vulnerable to climate change. Small-scale fisheries provide jobs for approximately 47 million people, with about 12.5 million directly engaged in fishing and another 34.5 million engaged in post-harvest activities (IPCC, 2014b, p. 1701). These fisheries, especially in tropical countries, are often vulnerable due to an number of factors, including: the high exposure of low-latitude regions to the impacts of climate change; poor governance and management structures; and little or no data on fish stocks (IPPC, 2014a, p. 776). The bulk of the world’s aquaculture production is done in the tropics, where population densities are high, which also makes the sector especially vulnerable (De Silva and Soto, 2009).

Box B4.1 Global mapping of national economies' vulnerability to climate change impacts through fisheries

Following the IPCC definition of vulnerability, which integrates exposure, sensitivity and adaptive capacity, and using available data, the relative vulnerability of national economies to the impacts of climate change on fisheries has been calculated for 132 countries. The analysis indicated that, in Africa, there were 16 least developed countries, and in Asia, three least developed countries, that were listed

among the most highly vulnerable countries. Unfortunately, limited data precluded many SIDS 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 experience major physical impacts, the region's adaptive capacity to respond to climate change is relatively low and fish consumption high. As a result, some economies are highly vulnerable to even minor changes in climate and temperature. In the northern hemisphere, the Russian and Ukrainian economies were ranked highly vulnerable due to the impact higher temperatures are expected to have on their fisheries and their low adaptive capacities.



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

Climate-smart fisheries and aquaculture

Climate-smart approaches in fisheries and aquaculture address three key objectives. The first objective is connected to the overarching goal of achieving sustainable food systems, and encompasses the environmental, social and economic aspects of fisheries, including both commercial fleets and artisanal fisheries, and aquaculture. The second objective focuses on the need to reduce the vulnerability of the sector to the impacts of climate change and build the sector's resilience so that it can cope with the impacts climate variability and climate change are projected to have on the availability of resources, and with natural disasters caused by an increased incidence of severe weather episodes. The third objective is to enable the sector, where possible, to contribute to the mitigation of greenhouse gases emissions during the harvest and production stages and throughout the entire value chain, which, given the high level of processing, transport and marketing activities involved in the sector, is extremely important.

Climate-smart approaches in this sector are connected with most, if not all, of the major cross-cutting themes of sustainable development. As in other sectors, several issues need to be recognized and reconciled for climate-smart

approaches to become the default pathway for development. Existing practices, such as ecosystem-based management, fall within climate-smart approaches (see Box B4.2 and Annex 1).

Key considerations include the need to:

Expand the evidence base:

Available data on observed and projected climate change impacts have become more detailed for the individual chemical and physical drivers of change, especially in the oceans. However, the combined effects of all the drivers are still limited. More detailed knowledge on the regional and subregional impacts of climate change is required to understand the vulnerabilities of individual ecosystems, capture fisheries, aquaculture systems, food processing and trade, and the communities and societies that are directly or indirectly dependent on them. Expanding the evidence base regarding the levels of exposure, vulnerabilities and risks will allow for the formulation of well-targeted adaptation strategies. Further research on the sector's potential to mitigate climate change by reducing emissions and/or improving carbon storage would also support climate-smart development. Given the growing global demand for fisheries products and the importance of fish products for the survival of the most impoverished, understanding how to align adaptation and mitigation strategies and at the same time increase production in an environmentally responsible manner is key for sectoral development and global food security.

Support enabling frameworks:

In many countries, fisheries and aquaculture play an important role in supporting livelihoods and safeguarding food and nutrition security. To maintain or improve these contributions, well-structured, enabling policy frameworks and investment plans need to be developed and implemented. These frameworks and plans should not address fisheries and aquaculture in isolation, but consider how the National policy-makers should have sufficient capacities to be able to engage with local government authorities and participate in international fora on climate change and fisheries and aquaculture. Strong institutions that are well embedded within the political landscape, are better positioned to identify and address specific gaps in capacity, efficiency and system resilience for the sector, particularly those gaps that are likely to increase under climate change, and identify generic or specific actions to address these gaps. Strong local institutions that can empower, enable and motivate small-scale fishers and fish farmers are essential, as they provide opportunities for the reciprocal exchange of knowledge (traditional and modern), capacity needs and future plans.

Enhance financing options:

Innovative mechanisms that link and blend climate finance and investments to sector-specific needs are essential for developing and implementing climate-smart fisheries and aquaculture. The Green Climate Fund, which promotes low-emission and climate-resilient development pathways, is one of the key international financing instruments for the sustainable agricultural development, including the fisheries and aquaculture sector. Strong and all-encompassing Nationally Appropriate Mitigation Actions and National Adaptation Plans are important policy instruments for creating links to domestic and international financing. National budgets and official development assistance will continue to be main sources of funding. Integrating climate concerns into sectoral planning and budgeting is a prerequisite for successfully addressing climate change at national and subnational levels.

Implement practices in the field:

Small-scale fishers and fish farmers are the primary sources of knowledge about their environment, aquatic ecosystems, fish and other aquatic species and local climatic patterns. Adopting climate-smart fisheries and aquaculture should be closely linked to local fishers and farmers' knowledge, requirements and priorities. Suitable climate-smart strategies can be identified through the participation of fishers and farmers in local projects. Climate-smart approaches must be recognizable and actionable by policy agents in order to work effectively with practitioners and beneficiaries at all levels. Capacity building for non-governmental stakeholders improves their ability to support sustainable national and subnational policies. In addition, in some developing countries, support for local associations, in some cases leading to fisheries or farm cluster certification, has been brought about through interactions in field with industry and/or the government. More interventions in the field with all stakeholders involved would improve the development of good practices and speed the uptake of field-tested climate-smart adaptation measures by local communities that are most vulnerable to climate change.

Fisheries and aquaculture have distinct characteristics, including:

- 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 particularly rapid interactions of pollutants and pathogens in aquatic environments, which are being affected by various drivers of acidification and climate change, and creating potential risks to productivity, stocks and human health;
- 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.
- the significant level of social and economic dependence on wild fish stocks in small- and large-scale ecosystems, which are associated with a wide range of activities that are driving climate change;
- social issues related to the 'last-resort' or emergency uses of fisheries resources, and the widespread social marginalization and poverty in fishing communities along many of the supply chains;
- very limited development of risk and insurance markets for both capture fisheries and aquaculture, and few mechanisms for community-based responses to less stable conditions;
- the continued challenge of governance issues, particularly for fisheries resources, including the substantial levels of IUU fishing, and widespread fleet overcapacity;
- the transboundary nature of major resource systems, including areas beyond national jurisdiction, and the political complexity of resource management systems;
- the high concentration of aquaculture in the tropics and very populated areas;
- the significant contribution to food security and nutrition made by small-scale fisheries, which make affordable fish available and accessible to poor populations and are a key means for sustaining livelihoods in marginalized and vulnerable populations, compared to large-scale industrial fishing (HLPE, 2014).

In such a complex environment, 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. There is considerable knowledge on how to build and maintain the resilience 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[iii] articulates 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 a

range of issues, including the prevention of overfishing; the minimization of negative impacts of fisheries and aquaculture to aquatic ecosystems and local communities; and the protection of human rights for a secure and just livelihood. The Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication[iv] (FAO, 2015b) provide complementary guidance to the Code of Conduct with respect to small-scale fisheries. The Voluntary Guidelines call on all parties to recognize and take into account the impact of natural disasters and climate change on small-scale fisheries and recommend that appropriate adaptation, mitigation and aid plans be taken, in line with human rights principles. The ecosystem approach to fisheries and aquaculture provides the strategies and tools for implementing the Code of Conduct and the Voluntary Guidelines and proposes a holistic, integrated and participatory approach for the sustainable management of fisheries and aquaculture systems under all conditions, including under climate change and climate variability. The direct benefits of implementing the ecosystem approach are outlined in Box B4.2.

Detailed information on the ecosystem approach to fisheries and aquaculture can be found in Annex 1. Improving the general resilience of fisheries and aquaculture systems can reduce their vulnerability to the impacts of climate change and climate variability on resources and to severe weather episodes that trigger natural disasters. Systems rich in biodiversity are less sensitive to change than overfished systems with little diversity. For example, healthy coral reef and mangrove systems, which provide habitat to a wealth of biodiversity, provide many benefits, including acting as natural barriers to physical impacts of climate change. In addition, healthy, sustainably managed mangrove systems and seaweed farms have high capacities for sequestering and storing carbon. Well managed mangroves and seaweed farms also provide the ideal habitat for many fish species' reproduction and feed requirements and contribute to the sustainable supply of fish. Improved resilience, including encouraging the consumption of a greater diversity of fish species, utilizing by-products from processing and reducing waste along the value chain, can contribute to stabilizing the availability of nutritious food and securing income for communities that are directly or indirectly dependent on capture fisheries and aquaculture for their livelihoods. Safeguarding a stable supply of fish and fisheries products can enable the development of stronger social systems and create livelihood options from within the communities that rely on fisheries and aquaculture.

Box B4.2 Direct benefits of implementing the ecosystem approach to fisheries and aquaculture include:

- Supporting resilient ecosystems, communities and governance structures and reducing the exposure of the sector to risks, by increasing the aquatic systems' potential to absorb and recover from change, making communities engaged in fishing and aquaculture less sensitive to change, and increasing the sector's adaptive capacity;
- Improving the efficient use of natural and human resources for food and livelihood security;
- Supporting intersectoral collaboration, particularly the integration of climate change adaptation and disaster risk management in fisheries and aquaculture strategies, and integrated resource management (e.g. integrated coastal zone or watershed management and water planning);
- Promoting integrated monitoring and information systems that incorporate scientific and local knowledge;
- Improving general awareness and knowledge of climate change inside and outside the sector;
- Promoting context-specific and community-based adaptation strategies;
- Avoiding 'maladaptation' (e.g. overly rigid fishing access regimes that inhibit fisher migrations and adaptation actions that increase fishing in an overfished fishery);
- Embracing adaptive management, decision-making under uncertainty and the precautionary approach;
- Promoting natural barriers and defences against variability and change, and natural disasters rather than hard barriers that affect the ecosystem; and
- Unlocking financial potential.

B4 - 4.1 Sustainably increasing productivity and efficiency and addressing constraints to market access

There are two principal approaches for increasing productivity and efficiency in aquatic systems. For capture fisheries, the essential issues are: reducing excess capacity and ensuring the fishing effort is following improved fisheries management; and maintaining healthy and productive stocks and systems. Although total fishery production might not be increased to any significant extent, there is room to reduce costs, particularly fuel costs. A reduction in fuel costs, most likely brought about by a reduction in the amount of fuel used, would improve economic efficiency and reduce greenhouse gas emissions. Better stock conditions may also improve the quality of the catch. Performance could be enhanced by adopting improved handling practice that reduce losses during harvesting (e.g. the icing of fish or the use of drying ovens when refrigeration is not available) and lowering the amount of bycatch and/or improving its utilization. Finally, by reducing waste along the fish value chain, which is estimated to be approximately 30 percent of total production, the amount of fish needed to meet nutritional needs could be reduced, which would reduce the pressure on overutilized fisheries.

For aquaculture, the primary emphasis is on sustainably intensifying production, using more fully integrated systems, improving productivity of farmed strains, making feeding more efficient and reducing losses from disease (De Silva and Soto, 2009; Troell *et al*., 2014a). All of this must be accomplished without compromising the nutritional quality and safety of the product (Beveridge *et al*., 2013). Dependence on fishmeal and fish oil is often cited as a primary constraint to growth for aquaculture (Hasan and Halwart, 2009; Hall *et al*., 2011; Little *et al*. 2016). Although this dependence is slowly declining, as alternative feeds are being developed, fishmeal and fish oil are still used as feed ingredients (Tacon and Metian, 2008; Hasan and Halwart, 2009). In both inland and coastal areas, it is also increasingly likely that aquaculture development will face constraints related to the availability of land and water resources (Troell *et al*., 2014b). These constraints are a consequence of increased competition from other sectors and changing agro-ecological conditions. In some cases, aquaculture production systems may need to be relocated (FAO and World Bank, 2015). Within the aquaculture subsector, aquaponics presents a potential option for increasing efficiency in ways that address existing constraints (see Box B4.3 for an overview on aquaponics).

In food processing and other activities that add value to fisheries and aquaculture products, efforts should be made to reduce losses and waste, and produce more product in less time. Increasing the efficiency of product storage and distribution also deserves attention.

The overarching principles of sustainable fisheries and aquaculture are found in the FAO Code of Conduct for Responsible Fisheries and related guidelines. These principles provide guidance on the approaches to follow to achieve sustainable increases in productivity and efficiency. The principles may be progressively elaborated upon with more specific guidance as more experience is gained in climate-smart policies and practices. Tools and best practices for improving efficiency and sustainability that cover the social, economic and ecological aspects of fisheries and aquaculture are under development and being tailored to accommodate climate change and climate variability. However, one of the key constraints in developing effective advice on adaptive management is the often limited data and information on which to base concrete decisions.

Box B4.3 An Overview on Aquaponics - Integrating Aquaculture and Hydroponics

Aquaponics is a symbiotic integration of two mature food production systems: aquaculture, the practice of fish farming, and hydroponics, the cultivation of plants in water without soil. The two production systems are combined within a closed recirculating system. In a standard recirculating aquaculture system, the

organic matter ('waste') that builds up in the water needs to be filtered and removed to keep the water clean for the fish. In an aquaponic system, the nutrient?rich effluent is filtered through an inert substrate containing the rooting system of plants. Here, bacteria metabolize the fish waste, and plants assimilate the resulting nutrients. The purified water is then returned to the fish tanks.

Aquaponics is one type of integrated agriculture/aquaculture technique that meets the criteria of climate-smart agriculture. It sustainably increases food security by increasing agricultural productivity and incomes. Producing value-added products (both fish and vegetables), aquaponics also contributes to reducing watershed pollution, which often originates from fertilizer runoff and aquaculture effluent discharge. It has the potential to deliver higher yields of produce and protein with less labour and land, fewer chemicals and a fraction of the water usage. At the same time, aquaponics is a resilient system that can be adapted to diverse and changing conditions. Being a strictly controlled system, it combines a high level of biosecurity with a low risk of disease and external contamination, while producing high yields without the need for fertilizers and pesticides. Moreover, it is a potentially useful tool to overcome some of the challenges traditional agriculture is facing, such as shortages fresh water, climate change and soil degradation. Aquaponics works well where the soil is poor and water is scarce, for example in urban areas, arid climates and low-lying islands. Although research is scant, aquaponics produces relatively fewer greenhouse gas emissions to produce the same amount of product. This is because of the high efficiency of feed, the reduction of mineral fertilizer, and the lower energy expenditure as there is no need to till, plough or work the soil. The highly efficeint use of space means that less farm land is required to grow the same amount of food.

However, commercial aquaponics is not appropriate in all locations, and many aquaponic businesses have not been successful. Large-scale systems require careful consideration before financial investment, especially regarding the availability and affordability of inputs (i.e. fish feed, building and plumbing supplies), the cost and reliability of electricity, and access to a significant market willing to pay premium prices for local, pesticide-free vegetables. Aquaponics combines the risks of both aquaculture and hydroponics, and expert assessment and consultation is essential. As a relatively new technique, aquaponics is subject to ongoing research around the world from both knowledge institutions and entrepreneurs, who are looking at ways to develop economies of scale, reduce capital expenditure, and make the systems and technology simpler and more available to small- and medium-scale farmers.

FAO has started work supporting aquaponic development and has published a technical manual on the subject, *Small-scale Aquaponic Food Production* (FAO, 2014). During the Thirty-first Session of the FAO Committee on Fisheries, aquaponics was raised by four Member Countries (Cook Islands, Indonesia, Kenya, and Mexico) as a subject that deserves increased attention. A side event at the session included a presentation by the Indonesian delegation on Yumina, a form of aquaponics used in homesteads across the country. As a follow-up, Indonesia, with support from FAO and the South-South Cooperation team, conducted a regional aquaponic technical training workshop in Indonesia in 2015 to train trainers from other countries in the region. Separately, FAO convened an aquaponic training workshop for countries in the Near East and North Africa. FAO has previously supported aquaponic development in Antigua, and will conduct regional training and build demonstration sites in other Caribbean countries.

Aquaponics has the potential to support economic development and enhance food security and nutrition by fostering an efficient and integrated use of resources, and will become another option for addressing the challenge of charting a sustainable path to global food and nutrition security

FAO, 2016a

B4 - 4.2 Reducing vulnerability and increasing resilience

Reducing vulnerability

The risks that climate change presents to the fisheries and aquaculture sector are similar to those in other agriculture sectors. However, there are risks that are specifically related to aquatic environments and the open access nature of fisheries that are not shared, or shared to a much lesser degree, by terrestrial systems. Relative to terrestrial food production systems, significantly less research has been conducted on the risks to the fisheries and aquaculture sector. There remain many unanswered questions about the ultimate impacts of climate change on fish resources, especially at regional and local levels. However, the impacts that have been identified are generally negative for the tropics and SIDS. In northern latitudes, the impacts could provide potential gains to fisheries.

It should be noted that changing conditions may bring development opportunities to tropical multispecies fisheries, as they may improve ecosystem functions and increase productivity. Rising sea levels could also create more opportunities for brackish water aquaculture. Practical actions to reduce vulnerability and increase resilience have typically focused on addressing the uncertainties and risks related to livelihoods and production systems, which are exacerbated by climate variability and increasingly severe weather episodes.

Decisions as to which options to select will depend on a number of factors: the location and scale of change and the attendant risk to the dependent communities; the impacts and the perception of their effects; and the cost, complexity and time required to implement countermeasures. To increase the overall resilience of a system, priority may be given to small and inexpensive changes in practices that can quickly reduce the risks for the most vulnerable. Box B4.4 provides an overview of ways to improve resilience with moderate levels of resources in culture-based fisheries.

When a system's exposure to climate change becomes severe, and adaptive capacity is limited, small and inexpensive actions may not be enough to increase the system’s resilience. Implementing small and inexpensive, but insufficient actions, could provide a false sense of security (e.g. in the case of extreme events) when the long-term impacts are projected to become more and more severe. Faced with increasing severity, a long-term strategic approach may be needed that may involve, for example, the development of new technologies, improvements in the accessibility of finance, or changes in livelihoods for communities at risk.

Premature overinvestment in expensive forms of protection may dangerous, in that they may deprive communities of important financial resources and protect only some sectors of the population. Protecting and strengthening one area, community or activity can result in a trade-off that leaves others relatively unprotected, and these potential trade-offs should be considered in policy decisions. Over longer periods, infrastructure development and the relocation of people towards safer or less vulnerable areas may be the solution. Early investments oriented toward short-term solutions may serve merely to delay the inevitable.

Marine and inland fisheries and aquaculture farms are likely to continue to be affected by climate change, climate variability and extreme events in a number of ways, including: reduced yields, changes in the variety of fish species, the nutrients available for coastal fisheries and aquaculture farms, sea level rise, and shifts in production due to rising temperatures, acidification and pathogens. Annex 2 provides a non-exclusive list on impact areas and potential responses for reducing vulnerability in fisheries and aquaculture. Given that specific fisheries and aquaculture systems will be affected differently by the impacts of climate change, Annex 2.2 outlines possible response options to these impacts in a range of fisheries systems. Figure 1 in Annex 2.3 presents the impacts and response options in specific aquaculture systems. The impacts and response options in specific post-harvest (processing, marketing and trade) systems are outlined in Annex 2.4.

The response options provided in Annex 2.1 – 2.4 take into consideration the potential level of severity of change. The levels of disturbance are categorized as: minor disruptions, which are relatively easy 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 already familiar patterns; and major disruptions whose frequency and/or magnitude expose the system to unsupportable levels of risk, making it imperative to undertake modifications, some but not all of which could be based on existing systems.

In the broader response to uncertain vectors of change, approaches that incorporates climate-smart disaster risk reduction and disaster risk management are also of value. These approaches originated in post-disaster interventions (e.g. storms, floods, tsunamis) where there was the need to measure and reduce similar risks to vulnerable communities. However, they can be applied more proactively and used to anticipate and respond to the complete profile of climate change impacts in a given context. These approaches can be improve the connections to response needs in areas where storms are also associated with sea level surges, salinization of ground water, and/or the destruction of nursery habitats.

Often interactions with other sectors that are also affected by climate change must be considered. For example, inland fisheries are particularly sensitive to policies and actions outside the sector, as fresh water resources have many other uses and are often exposed to pollutants. Similarly, many coastal environments are increasingly subject to changes in freshwater runoff, agricultural intensification, growth in the industrial and energy sector, expanded urbanization and transport, and the development of tourism. For aquaculture, there are also interactions and trade-offs 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 designing policies to address climate change and other aspects of development that can deliver cross-sectoral benefits are key challenges.

Box B4.4 Options for culture based fisheries to improve climate resilience

Culture-based fisheries is typically a perennial and seasonal stock enhancement process. It is practiced in smaller water bodies and even flooded fields, which under normal conditions would not support a significant fishery through natural recruitment. In culture-based fisheries, 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. Culture-based fisheries has also become a major part of government strategies to increase fish production for food and improve livelihoods, particularly in impoverished rural communities (Amarasinghe and Nguyen, 2009).

Culture-based fisheries as an environmentally friendly food production system

In many instances, culture-based fisheries is seen as a practice with a small environmental footprint and a good example of multiple, effective use of water resources (De Silva, 2003). Culture-based fisheries does not consume water or external feed resources. The only input is the seed stock. The stocked species are selected in a manner that fills vacant food niches and ensures that natural food production can maintain the growth and well-being of the stock. Consequently, the yields are similar to wild capture fisheries but less than in most intensive aquaculture practices. However, culture-based fisheries is environmentally friendly, the costs are minimal and there are no emissions related to feed. 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 fish production and food security in rural communities.

The possibilities of stocked fish mingling with wild counterparts are higher than in normal aquaculture practices. For this reason, whenever possible, indigenous fish species are recommended for culture-based fisheries in purposely constructed, artificial water bodies. The stocking or enhancement of open waters is far more complex and raises a range of issue relating to the mixing of farmed and wild stocks, genetic introgression and disease. The hatchery bred stocks that are introduced should originate from well

managed broodstock. Ideally, the broodstock would originate from wild stocks and be as close as possible to the wild type. In all cases, risk assessment is recommended before stocking to ensure that potential downstream impacts on the wild stocks and the environment are identified and mitigated.

Culture-based fisheries sensitivity to climate change and adaptation potential

As in all primary production activities, culture-based fisheries cycles are subject to the elements, primarily rainfall patterns, which entails a certain degree of unpredictability in the water levels. This is beyond human control. The available mitigating measures will involve careful planning to accomodate the hydrological cycle of the waterbodies. This might involve, for example, making adjustments in stocking and harvesting. Risks are associated with the greater frequency of flash floods, changes in monsoonal rain patterns and longer periods of dry weather, all of which are attributed to climate change and can have an impact the productivity of the system. In seasonal or perennial waters bodies, stocking is best done when the water body is filling up or full, and harvesting often takes place when the water level recedes. In areas where a large number of water bodies are used for culture-based fisheries, there may be a seasonal glut of fish at harvest, which can affect prices. Ideally, organizing marketing activities so that sales are staggered can help stabilize prices. Culture-based fisheries fits within an ecosystem management perspective and can be a sustainable and successful food production strategy, if appropriate precautions and strategies are in place. This requires both coordination within the fishery sector and with water management authorities to ensure that water bodies are not drained unexpectedly.

Increasing resilience

It has been observed that marine and inland fisheries and aquaculture resources and those dependent on them are likely to continue to be affected by climate change. Depending on the region, these affects can either be positive or negative. Response strategies for different fisheries and aquaculture systems, taking into account the severity of (potential) impacts are outlined in Annex 2. These strategies aim to preserve the natural environment and related ecosystem services that communities and societies directly and indirectly depend on. When designing and implementing these strategies, several key principles to base analysis and action should be included:

- 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.
- Trade-offs 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.
- If vulnerability is addressed only selectively or partially, remaining vulnerabilities may jeopardize or even negate any positive effects.
- People with resilient livelihoods are better able to withstand damage, recover and adapt to change.
- Unresolved issues outside the fisheries and aquaculture sector may limit the potential for building resilience. The analysis for identifying best adaptation and disaster risk reduction strategies should therefore understand the fisheries and aquaculture sector in a wider setting (e.g. the socio-economic situation, the status of other environmental resources, policies outside the sector that entail implications for its sustainability).

B4 - 4.3 Reducing and removing greenhouse gases

Greenhouse gas emissions from fisheries and aquaculture are associated with various aspects of production and distribution. The management of the aquatic ecosystem has important potential for reducing net greenhouse gas emissions through the natural sequestration of carbon. One possible mitigation option is aquatic biofuel production, which could be linked with fisheries and aquaculture production. There are also potential connections with mitigation efforts in the energy sector in areas such as hydropower and coastal and offshore renewable energy. The next section address three areas: the sector's own contribution to greenhouse gas emissions 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 fisheries and aquaculture in reducing emissions

Information on greenhouse gas emissions from aquatic food production and distribution systems and the potential to reduce them is becoming more clearly understood (Hall *et al*., 2011; Poseidon, 2012; Muir, 2012; Waite *et al*., 2014). For capture fisheries emissions are primarily related to fuel use. The nature of these emissions and their levels depend 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). Emissions are also determined by market forces and the management of fishing capacity. For example, when too many vessels chase after fewer and fewer fish fuel use tends to increase. Emissions of particulate 'black' carbon could significantly add to current estimates, but this issue needs further investigation. For aquaculture, feed is considered to be the primary determining factor for emission levels, with fertilizers being a secondary factor (FAO, 2016c). Emissions tend to increase as aquaculture production progresses from an extensive system, in which there is no treatment and/or only partial fertilization, to semi-intensive systems which use fertilizers and/or partial feeding, to intensive systems, in which the stock is completely nourished on feed. Fuel and energy used to exchange and treat the water, and power service vessels, vehicles, and equipment also generate carbon dioxide emissions, but usually at much less significant levels. The effects of methane and nitrous oxide in sediments and the water column, which are relatively undetermined, are also potentially important and require further study.

The processing of fish and aquatic animals ranges from simple artisanal drying and smoking to tightly controlled seafood preparation using high-specification packaging and labelling. In the processing stages, energy use is the primary determining factor for greenhouse gas emissions. There are wide variations in emissions depending on local practices, input variations (e.g species, sourcing, quantity and quality) and operating efficiency. Water used in food processing may also be an important factor in determining greenhouse gas emissions. Aquatic foods may travel considerable distances in a range of forms and in various states of perishability. During transport, greenhouse gas outputs are usually directly related to fuel and 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-depleting 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 relatively high levels of greenhouse gas. Cooled and frozen product that require less time-critical transport methods (e.g. ship-borne reefer and freezer containers) generate fewer emissions. 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 the lowest levels of emissions.

The ratios of greenhouse gas emissions per tonne of fish and aquatic foods at the production, distribution and retail stages are similar to those for other foods. Emissions at first sale account for typically 25-40 percent of total outputs. However, these figures vary widely. Limited numbers of comparative assessments of carbon dioxide equivalents per kilogram (kg) across the different food production systems suggest that fisheries operations that use

high amounts of fuel (e.g. poorly catching trawl or dredge fisheries) combined with energy-intensive post-harvest processing can be among the most greenhouse gas-intensive food systems. Passive fishing gear systems or lower trophic level aquaculture (e.g. bivalves, seaweeds) can produce as much foods as most systems of meat or animal protein production, but release far fewer emissions. The expansion of these systems has the potential to contribute to strategic shifts in consumption patterns and reduce global greenhouse gas emissions.

Box B4.5 provides an overview on a comparative analysis conducted by Hilborn and Tellier (2012) on the energy efficiency of fisheries production systems.

Box B4.5 The environmental costs of New Zealand food production

In New Zealand, fisheries had a lower impact in terms of water and fertilizer use, eutrophication potential and antibiotics when compared with dairy and meat production. Most fisheries also had lower levels of greenhouse gas emission 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 healthy 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. Compared to other countries, the New Zealand dairy and meat industries were more efficient in energy use and greenhouse gas emissions. 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	FreshWater	Fertilizer	Pesticides	Antibiotics	Surface Area Impacted	Greenhouse gases	Eutrophicatin potential*	Acidification potential**
	Megajoules	(litres)	(g)	(kg)	(mg)	(m2)	(kg CO2)	(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

The role of fisheries and aquaculture in supporting the natural removal of emissions

The significant role oceans and coastal margins play in capturing and sequestering carbon is becoming increasingly understood and recognized. It is estimated that around 93 percent of global carbon is stored in aquatic systems, and around 30 percent of annual emissions are sequestrated in aquatic environments, primarily in mangroves, seaweeds, seagrasses, floodplain forests and coastal sediments (Nellemann *et al*., 2009). To improve the sector's capacity to remove emissions, it is of primary importance to halt the disruption of carbon sequestration caused by habitat destruction and improve the often inadequate management of fisheries and aquaculture. Secondly, there may be valuable opportunities to enhance sequestration by expanding planted areas of mangroves and floodplain forests. This expanded planting would also lead to healthier ecosystems and a greater abundance of aquatic species, which would contributed to improving the quantity and quality of local and regional ecosystem services. A higher abundance of aquatic species, if managed sustainably, can provide stable livelihoods and safeguard food and nutrition security. In developing carbon funds to support greenhouse gas sequestration in aquatic systems. attention needs to be given to ensuring that communities that rely on fisheries and aquaculture are properly represented and benefit from this funding.

There is also potential to explore the role of aquaculture in carbon sequestration. Primary options include integrated multitrophic aquaculture (IMTA), where molluscs and seaweeds are grown as by-products using waste from more intensive aquaculture; and systems where the sediments in aquaculture cages or ponds are managed to enhance sequestration. Although these systems offer potentially valuable means of storing carbon, removing the carbon over the long term would require more secure means of disposal.

The role of fisheries and aquaculture in providing alternative energy sources

There is tremendous technical and environmental interest in developing renewable aquatic energy. Options include aquatic substrate biofuels, hydropower and other aquatic-based energy systems that exploit the energy potential of tides, currents, waves and wind. There are also opportunities for the physical integration of aquatic-based energy systems with newly developing infrastructure, such as offshore wind and wave installations. There is particular interest in algal biofuels based on either microalgae, which are typically cultivated in coastal ponds or intensive stirred tank systems, or macroalgae (seaweeds), which is grown in conventional culture systems. The use of microbial enzymes to produce fuels, such as bio-ethanol and biodiesels, is an already established practice, and efficiency and yields are increasing. This is particularly the case with genetically engineered bacterial enzyme systems capable of digesting celluloses and, in some cases, converting it direct into biofuel. Genetically engineered 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 attractive. It should be noted that, as is the case for terrestrial biofuels, algal biofuels will only provide an emission displacement function; they will not lead to a net sequestration of carbon.

Strategic climate-smart approaches for fisheries and aquaculture

Chapter B4.4 described the three main objectives of climate-smart approaches for fisheries and aquaculture. To create an effective framework to meet these objectives, these thematic areas need to be addressed at a range of strategic scales and levels. The following practical and operational options can be considered and 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 best practices become more clearly established.

B4 - 5.1 National and regional level approaches

- To meet the growing demand for food, the sustained long-term production of all food types, including fish and seafood, must be secure. In the case of capture fisheries, this requires sustaining the fisheries natural resource base and involves making accurate assessments of these resources and aquatic ecosystems. The scientific methods and capacity for such assessments need to be greatly expanded, especially in developing countries. Assessments should focus not only on higher-value species and larger fish, but also on all fish species of all sizes that contribute to food security and nutrition.
- Build the capacity for developing strategic national and international initiatives that combine mitigation and adaptation activities, including disaster risk reduction and disaster risk management, in the fisheries and aquaculture sector. Link this work with programmes in other sectors and other areas of development, and with funding mechanisms, including those directed to climate change and the reduction of greenhouse gas. Define the most critical approaches and timelines for mobilizing actions and establish indicators for proposed outcomes.
- Develop practical perspectives on national and regional aquatic food supply potentials under climate change scenarios to help shape 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 for example through the movement of stocks, growth conditions for aquaculture, other locational advantages, what sort of investment is required to benefit from this, and what might be the trade and value-added opportunities?
- Carry out strategic analyses and develop institutional and human capital. 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 that focus on markets and fisheries and aquaculture products to increase flexibility in supply and demand, and strengthen the resilience of the sector to ensure it can deliver a sufficient supply.
- Mainstream climate change adaptation strategies related to fisheries and aquaculture, and food and nutrition security, into all aquaculture and fisheries policies and actions at national and subnational levels. This includes linking these strategies to agencies responsible for climate and weather research and predictions, undertaking specific studies and introducing, where needed, flexibility in management and governance mechanisms (HLPE, 2014).
- Engage in inclusive dialogue and analysis to build scenarios of the possible impacts climate change will have on food security and nutrition in the most vulnerable zones (e.g. coastal areas and SIDS) and develop and implement the appropriate responses through inclusive processes (HLPE, 2014).

B4 - 5.2 Strategic approaches for industry

- Assess and define strategic investments, particularly regarding infrastructure for protecting and improving production capacities and the supply chain. Define tradeoffs between 'hard' engineering strategies, which would cover classic infrastructure, (e.g. roads, harbours, power supply, market and processing facilities and services) and macro-level aquaculture protection (e.g water supply and drainage systems) and 'soft'

strategies in which adaptation actions would be done with minimal expenditures on infrastructure.
- Define and develop landscape-level interactions with other sectors that address hydrological planning, coastal protection, and their relationships with aquatic habitats. Define and establish rules, tools and models for achieving this integration in ways that cover biochemical, ecological and social issues.
- Provide strategic opportunities for innovative forms of integration, such as managed aquatic systems and habitats that are linked with the generation of renewable energy and other aspects of energy production and consumption.
- Undertake subsector initiatives to identify and promote best practices, formulate resilient supply strategies, and carry out focused research and development to reduce risk.

B4 - 5.3 Local approaches

- Carry out an analyse the local social, economic and policy context, which should cover, among other things, the economic status of various stakeholders; their livelihood options; human, social and financial capital; the institutional environment; and options for capacity building.
- Use capital and operating cost models to explore the implications of the different potential impacts of climate change (e.g. incidence and levels of flooding, rainfall and water exchange, temperature, salinity, algal blooms, and disease transmission). Generate viability profiles under different scenarios, and where relevant, develop location-based risk maps, using, for example, geographic information systems.
- Identify the practical aspects of risk reduction, which would include modifications in physical structures and storm and flood protection, changes in operating strategies, environmental management, diversified and segmented supply chains, cross-sectoral investments, a diversified mix of species, input options and markets. Link old knowledge to new options and build capacities.
- Where necessary, define and specify options for relocation, opportunities for policy interventions and investment, alternatives for sustainable livelihoods and possibilities for diversification.

Individuals and communities

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

B4 - 5.4 International markets and policies to build value chain resiliency

Event though there have been considerable efforts in the international community to negotiate agreements for responsible ocean and resource management and use, the sustainable use of aquatic resources remains a critical issue. The importance of the issue is reflected in the Sustainable Development Goals (SDGs): SDG14 focuses on oceans and SDG12 focuses on promoting sustainable production and consumption. It is not only fish stocks and aquatic ecosystems that are at stake. Vulnerable communities with few resources and the many related activities along the food value chain (e.g. marketing, distribution, transport, processing) depend heavily on fisheries and aquaculture resources, and as such, face substantial economic losses from declines in productivity of capture

fisheries and aquaculture brought about by climate change.

The first step in promoting sustainable fisheries markets and trade is to ensure that products are produced in a sustainable agricultural system right at the beginning of the supply chain. The FAO Code of Conduct for Responsible Fisheries explicitly states that one of its aims is to promote “responsible international trade”. However, twenty years after its adoption, many developing countries report that they are still struggling to fully implement the principles of the Code of Conduct. There has been a steady growing global demand and prices have risen for most commercially traded fish species, which has encouraged the development of fish export channels, as well as illegal fishing in national jurisdictions and on the high seas. IUU fishing has increased dramatically over the last decade, especially for high-value species, such as tuna, in the areas beyond national jurisdictions, and species, such as rays and sharks, that are listed in the Convention on International Trade in Endangered Species (CITES). Evidence from countries indicates that the implementation of the Code of Conduct for Responsible Fisheries and the ecosystem approach to fisheries and aquaculture management is not keeping pace with the pressures to meet the growing demand in international markets for fish and fishery products.

Climate change is expected to exacerbate the problems caused by unsustainable fisheries governance and trade practices. The dramatically rising share of fish exports from developing countries, which improves livelihoods and increases tax revenues, but also threatens the environment, is unsustainable. The full implications of climate change for international trade of fish and fishery products are not well known and require further study. Research at regional and national levels is especially needed to understand the links between changes in the abundance and distribution of resources and fisheries and aquaculture production. Once changes in production are fully understood, extrapolation to markets and trade flows can be made to highlight the potential winners and losers from climate-induced resource shifts, which have been reasonably well documented at the global level.

Clearly, climate change will increase uncertainties and raise risks in the supply of products from both inland and marine capture fisheries, at least until communities are able to adapt to changes in resource distribution. Rising temperatures in ponds and along coastal shelves, the increased incidence of disease due to higher temperatures, and higher incidence of escapes caused by severe weather episodes are also putting aquaculture at risk. Extreme weather events and sea level rise are anticipated to impact fisheries-related infrastructure, such as ports and fleets, which will further increase the costs of fishing, processing and trade (Chomo and DeYoung, 2015; ICTSD).

The expected impacts of climate change have the potential to alter the distribution of fisheries production, the competitiveness of exports and, ultimately, world trade patterns. While some regions may gain from expected resource shifts, others will have to make major adjustments, which may put the sustainability of some livelihoods at risk. Climate-induced movements in aquatic species used in the fisheries and aquaculture sector will demand that adaptation measure be undertaken at all stages of the seafood value chain (production, processing, marketing, exporting and importing), to cope with changing local and regional supplies.

Merino *et al*. (2012) have developed a model to estimate the impacts of climate change on capture fisheries production. The model predicts a six percent increase in potential yield from large commercially-valuable fish stocks by 2050, but this would not keep pace with expected rate of population growth. The authors propose that aquaculture could fill the gap between future supply and demand. However, intensification of aquaculture production will require technological advances to ensure that the increased production does not harm the environment.

Another study by Barange *et al*. (2014) has optimistic projections that global fish supplies will be able to meet rising global demand in 2050, but not without possible negative impacts on vulnerable regions. In response to a redistribution of resources resulting from climate change, trade patterns may need to change in order to deliver

products from regions producing a surplus to those facing deficits. It is likely, however, that the deficit regions will not have enough financial resources to pay for these imports.

Production conditions differ around the world, and local adaptation responses will be needed. Further research and data collection is required at the national and subnational levels to ensure that model projections are useful for the policy-makers who are responsible for allocating limited financial resources to assist vulnerable communities.

- Linking early predictions with production and eventually trade flows will require significant research efforts, especially in moving from global analyses to regional and national level studies.
- There needs to be more flexibility in existing management tools used by national governments and regional fisheries management organizations to open up adequate policy space for countries to adapt to changes in resource availability under climate change.

Fisheries subsidies that lead to overcapacity of global fishing fleets need to be rationalized to deal with their distorting effects on trade and their impact on resources. This discussion is ongoing within the World Trade Organization’s Doha Development Round and will hopefully lead to a more sustainable multilateral trade policies for capture fisheries.

B4 - 5.5 Transitioning to climate-smart agriculture

The definition and validation of climate-smart agriculture approaches for fisheries and aquaculture are in the early phases of development and dissemination. Applied research and practical solutions were shared at the first international conference on adaptation to climate change in the fisheries and aquaculture sector (FishAdapt, Bangkok, Thailand, 22-24 August, 2016). This FAO conference highlighted case studies describing the innovative means fishers and aquaculture producers have adopted to adapt to climate change; the support national governments have provide to the sector; and efforts regional and global stakeholders have made to address the issue. The conference also emphasized the need for additional FishAdapt conferences with a stronger focus on measuring local resource changes in productivity and formulating post-harvest policies to build resilience in seafood value chains.

There is little experience that can be used as a widely tested foundation for good practices, but a number of underlying principles have been identified and applied for defining concepts and measuring progress towards meeting agreed objectives. To assess the progress being made to achieve climate-smart agriculture, it is important to select and use practical indicators that address the shared needs for relevance, accuracy, accessibility and cost-effectiveness. It is also useful to apply generic indicators for climate-smart agriculture, such 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 the impacts on greenhouse gas emissions.

Also important are measures of resource use and impact efficiency, such as fuel, energy, land or water use per unit of output, and greenhouse gas emissions per unit of output. A number of more sector-specific indicators may also be pertinent. These may be used to varying extents in composite indicators, for example, in cases where social or environmental trade-offs need to be integrated with more conventional production-defined indicators. These indicators would cover 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 help specify the current conditions of the sector and the desired status over a given period.

Clearer definitions will also be required for the status and function of primary resources and their use in the sector.

This will serve to determine the current status of the sector, trends, the potential impacts of acidification and climate change, and how changes in the efficiency of resource use are delivering social and economic benefits.

It is possible to identify the current characteristics of the aquaculture and fisheries sector and the sector's vulnerabilities to acidification, climate change and climate variability. However, it is less easy to define the broad priority areas for action based on the projected impacts of climate change and the adaptive capacity of different systems, and the specific pathways and mechanisms for making these systems more robust and resilient. Based to some extent on similar issues in other agricultural sectors and sectors involved in natural resource management, 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.
- Social, legal, institutional, or economic and market-based incentives will be the key to making the transition to climate-smart agriculture. Ideally, financial or other benefits will make climate-smart agriculture self-sustaining, so that the additional impetus will only be required during the initial transition period. This impetus could be provided by increasing access to improved fisheries and aquaculture techniques and materials, modifying and strengthening institutions, building capacities and developing participatory monitoring systems.
- To meet emerging needs and avoid losses, some of the elements necessary for making the transition to climate-smart agriculture will require longer-term strategic investments in infrastructure, productive capacity, and improved products and services, including aquaculture stocks and feeds. The case for these investments, and the rate at which these investments need to be deployed, will have 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 sharing knowledge and experience and further strengthening institutions.
- Fisheries and aquaculture are embedded within complex ecosystems. It will be very difficult to provide accurate predictions about how these ecosystems will respond to climate change. To help define potential consequences and test responses, adaptive and low-cost monitoring systems must be established. These systems will need to be interactive and capable of building a strong and easily shared knowledge base across user groups.
- Markets and trade may help buffer changes in production that affect food security, consumer prices and supply-demand gaps. However, a better understanding is needed of the implications of climate change impacts and climate change policies throughout the entire supply and value chain. Appropriate policy measures need to be defined and implemented.
- Public and private sector investment and collaboration will be required to meet future demands and ensure the sector meets climate-smart agriculture objectives and delivers long-term benefits. Including multiple stakeholders in climate-smart agriculture planning will foster creative options for action and help to minimize the unintended consequences of chosen options.
- Many of the components of climate-smart agriculture can be strategically matched with broader development objectives connected to issues such as sustainability, social equity and biodiversity. Actions undertaken to meet these shared goals need to be integrated effectively.
- Improvement in basic fisheries and aquaculture management, including the reduction of overcapacity and overfishing, are key to building the resilience of fisheries and aquaculture systems, and supporting the sector’s effort to reduce or remove greenhouse gas emissions.
- The initiatives listed above, combined with changes in consumption behaviours and the way fisheries resources are used, would help ensure that the fisheries and aquaculture sector, despite the expected impacts of climate change, can continue to supply nutritious food to a growing population, (Merino *et al*., 2012).

The need to scale up research

The scientific information currently available and used to measure the potential impacts of climate change on productivity of aquatic resources is global in its scale. This has made it difficult for countries and regions to use this information when formulating climate change adaptation strategies. Depending on specific local conditions, potential production changes can diverge widely from global model estimates. Recent case studies have shown that the methodology chosen to assess the vulnerability of aquatic resources, and the communities that depend on them for their livelihoods, to climate change has a strong impact on the results. More work needs to be conducted at country level, and even ecosystem level, to improve the accuracy of projections regarding the potential changes in production from fisheries resources in river basins, lakes, estuaries and coastal shorelines.

It can be difficult to disentangle the impacts of climate change on productivity from the impacts of other activities. Other ecosystem stressors include: overexploitation of fish stocks due to overcapacity or mismanagement of resources, including illegal fishing; habitat degradation, such as destruction of mangroves, dams, and draining of wetlands; and irrigation and the overuse of industrial water that reduces water flow in rivers, lakes and estuaries and destroys sensitive fish breeding and feeding grounds. Information on reduced water flow, such as the volume of river runoff into coastal areas, is typically unavailable at local or national levels. This makes it hard to measure the impact on the productivity of fish stocks of reduced nutrients in coastal areas and increased salinity in estuaries. For small-scale fisheries in Lake Tanganyika, Lake Chad Basin and the Lower Mekong, there is evidence that the impacts on freshwater ecosystems of dams and population growth, which increases the demand for food and drives agricultural expansion, are overshadowing the impact of climate change (Conference on Adaptation to Climate Change in the Fisheries and Aquaculture Sector – FishAdapt, Bangkok, 22-24 August 2016).

If this information gap is to be overcome, communication and interactions between fisheries and aquaculture scientists and ocean-climate scientists needs to be improved. Projections provided by the climate scientists need to be tailored to meet the information needs of the sectors, especially fisheries and aquaculture, that will be most impacted by climate change. Given the lack of accurate data at national and local levels on how production will be affected by potential changes in aquatic species and by other human-driven stressors, there is significant uncertainty regarding projections for climate-related productivity changes. In light of this uncertainty, the ecosystem approach and the precautionary approach to management of aquatic resources remain the best way for countries to safeguard the sustainable harvest and utilization of their capture fisheries resources.

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 climate-smart agriculture simultaneously is not always possible and may not 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 explored further. 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 climate-smart agriculture approaches.

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Acronyms

IMTA	integrated multi-trophic aquaculture
IPCC	Intergovernmental Panel on Climate Change
IUU	Illegal, unreported and unregulated
SIDS	Small Island Developing States

Units of measure

g	gram
ha	hectare
kg	kilogram
m	metre
mg	milligram

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