Food and Agriculture
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United Nations

Summary of the FAO Fisheries and Aquaculture Technical Paper 627

# Impacts of climate change on fisheries and aquaculture

## Synthesis of current knowledge, adaptation and mitigation options

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# 1 Introduction

This document summarizes the content of a FAO Fisheries and Aquaculture Technical Paper 627 entitled *Impacts of Climate Change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options* (Barange *et al.*, 2018). The report was prepared primarily in response to the 2015 Paris Climate Agreement, which recognizes the need for effective and progressive responses to the urgent threat of climate change, through mitigation and adaptation measures, while taking into account the particular vulnerabilities of food production. Compiled by over 100 contributors, the report provides the most up-to-date information on the disaggregated impacts of climate change for marine and inland fisheries and aquaculture. The analysis is downscaled to sub-ocean and subregional areas and covers the differential dependency of countries on fish and fishery resources. The information, conclusions and recommendations provided are based on model projections, data analyses, as well as national, regional and basin-scale expert assessments. The results indicate that climate change will lead to significant changes in the availability and trade of fish products, with potentially important geopolitical and economic consequences, especially for those countries most dependent on the sector.

# 2 Why fisheries matter

Globally, fisheries and aquaculture make substantial contributions to the food security and livelihoods of millions of people. Excluding aquatic plants, total global production from the sector peaked at 171 million tonnes in 2016, with 53 percent of this total coming from capture fisheries and 47 percent from aquaculture (reaching 53 percent if non-food uses are excluded; FAO, 2018). The total landed value of the production in 2016 is estimated to have been USD 362 billion, of which USD 232 billion came from aquaculture production (FAO, 2018). Marine capture fishery production has been relatively stable since the late-1980s and there has been limited growth in inland capture fisheries. This has meant that growth in aquaculture production has been largely responsible for the remarkable increase in global food fish consumption between 1961 and 2016 of 3.2 percent per year, twice the human population growth rate. In per capita terms, this resulted in food fish consumption growing from 9.0 kg in 1961 to 20.2 kg in 2015, significantly contributing to global food security.

At the same time, the state of marine resources monitored by the FAO continues to decline. The fraction of marine fish stocks fished within biologically sustainable levels has exhibited a decreasing trend, from 90.0 percent in 1974 to 66.9 percent in 2015 (FAO, 2018), with developing countries faring worse than developed ones (Ye and Gutierrez, 2017). Considerable uncertainty remains over the status of many inland capture fisheries, which provide important contributions to global food demands, in particular to some of the poorest, most food insecure countries in the world.

An estimated 200 million people are employed, directly and indirectly, in the fisheries and aquaculture sector; women account for about 19 percent of those employed in the primary sector, but this rises to 50 percent if the secondary sector is also included (FAO, 2018). The livelihoods sustained by fisheries and aquaculture activities are thus crucially important in many coastal, riverine, insular and inland regions.

These facts demonstrate the critical importance of providing adequate responses to the threat of climate change: not only are fisheries essential for food, livelihoods and trade, but the state of the resource base limits their capacity to absorb climate shocks, particularly in developing regions where dependency on fisheries is greatest (Barange *et al.*, 2014).

# 3 Climate change: the physical basis

## What do we mean by climate change?

According to the Intergovernmental Panel on Climate Change (IPCC), climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere (e.g. greenhouse gases) or in land use.

Since 1988 the IPCC[1] has provided regular, evidence-based updates on climate change and its political and economic impacts. These updates comprehensively synthesize the internationally accepted consensus on the science of climate change, its causes and

1 The IPCC is the international body for assessing the science related to climate change, set up in 1988 by the World Meteorological Organization and the United Nations Environment Programme. The IPCC periodically issues special reports on specific themes, as well as global assessment reports based on published scientific information and taking stock of the most recent scientific evidence of climate impacts and proposed adaptation and mitigation responses. These reports are intended for policymakers and constitute the scientific basis for the international negotiations within the United Nations Framework Convention on Climate Change (UNFCCC). http://www.ipcc.ch

consequences. The Fifth IPCC Assessment Report (AR5) concluded that the changes in the climate system since 1950 are unprecedented compared with preceding decades to millennia. At the global level, the Earth's average surface temperature has increased by more than 0.8 °C since the middle of the nineteenth century, and is now warming at a rate of more than 0.1 °C every decade (Hansen *et al.*, 2010). Heat waves are more frequent now, even though the reliability of data and level of certainty vary across continents (Hartmann *et al.*, 2013). The largest contribution to this warming is believed to be from an increase in the atmospheric concentration of greenhouse gases (GHGs), which act like a thermal blanket around the planet and are responsible for allowing life on Earth to exist (IPCC, 2014). The IPCC AR5 also concluded that it is extremely likely that humans have been the dominant cause of the observed additional warming since the mid-twentieth century, through the association of GHG emissions with gas and oil combustion, deforestation and intensive agriculture. Most models and scenarios of future climates indicate that a large fraction of anthropogenic climate change is irreversible for centuries to come, even after complete cessation of anthropogenic GHG emissions.

The IPCC uses a hierarchy of climate models that simulate future changes based on a set of scenarios, which take the form of representative concentration pathways (RCPs) and which simulate possible ranges of heat or radiative forcing values in the year 2100, relative to pre-industrial values. Four RCPs are considered, based on radiative forcings of +2.6, +4.5, +6.0, and +8.5 $W/m^2$, respectively[2]. These RCPs are based on certain socio-economic assumptions (possible future trends, e.g. population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy).

According to projection models, it is estimated that for all RCP scenarios, except for RCP2.6, global atmospheric temperature change for the end of the twenty-first century is likely to exceed 1.5°C relative to the average of the 1850 to 1900 period. It is also likely to exceed 2°C for RCP6.0 and RCP8.5, and more likely not to exceed 2°C for RCP4.5 (**Figure 1**). Warming is also forecast to continue beyond 2100 under all RCP scenarios except RCP2.6, although there will be interannual-to-decadal variability and regional heterogeneity (IPCC, 2014).

## Observed and predicted impacts in the ocean

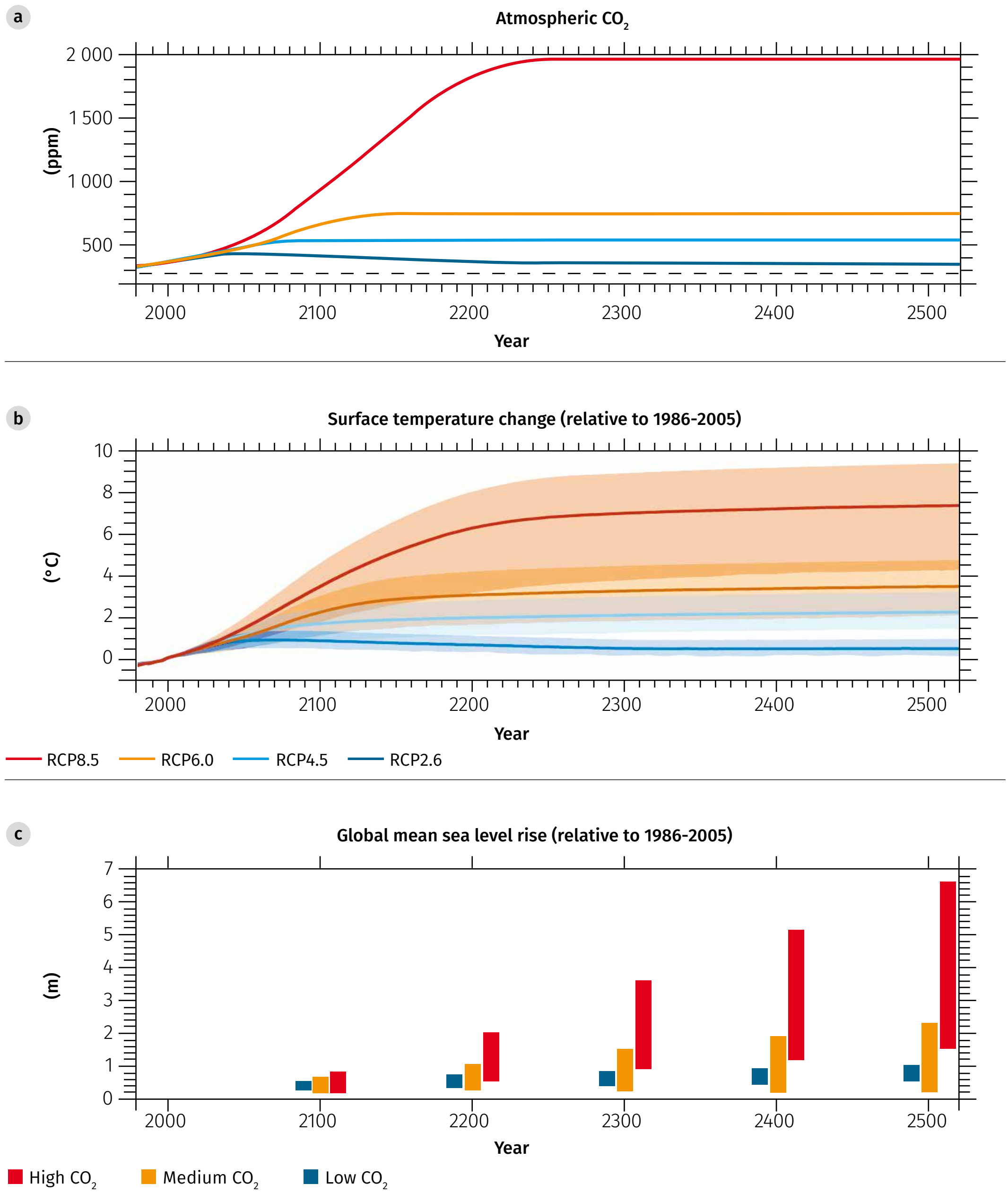
### Ocean warming

The ocean has absorbed more than 90 percent of the additional energy generated between 1971 and 2010 and absorbed 30 percent of the emitted anthropogenic carbon dioxide. Surface waters (0 to 700 m deep) warmed by an average of 0.7 °C per century globally from 1900 to 2016 (Huang *et al.*, 2015). Ocean temperature trends over this period vary in different regions but are positive over most of the globe, although the warming is more prominent in the Northern Hemisphere, especially the North Atlantic.

Dissolved oxygen levels in surface waters have decreased, consistent with expectations that ocean warming leads to a decline in oxygen supply, while tropical oxygen minimum zones have likely expanded over the last decades. This trend is expected to continue (**Figure 2**).

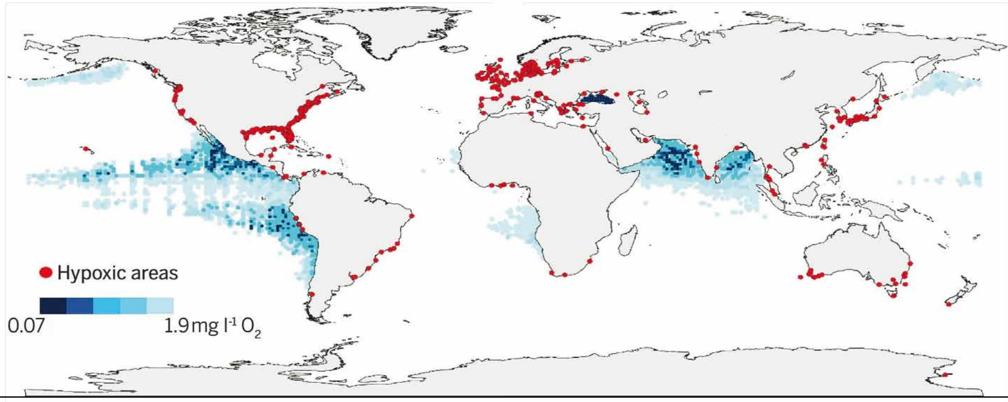
2 $W/m^2$= Watts per square meter

FIGURE 1. **(a) Atmospheric carbon dioxide $CO_2$ and (b) projected global mean atmospheric (surface) changes for the four RCPs up to 2500 (relative to 1986 to 2005). The dashed line on (a) indicates the pre-industrial $CO_2$ concentration. (c) Sea level change projections according to GHG concentrations (low: below 500 ppm as in RCP2.6; medium: 500 to 700 ppm as in RCP4.5; high: above 700ppm and below 1 500 ppm as in RCP6.0 and RCP8.5). The bars represent the maximum possible spread**




*Source:* IPCC, 2014

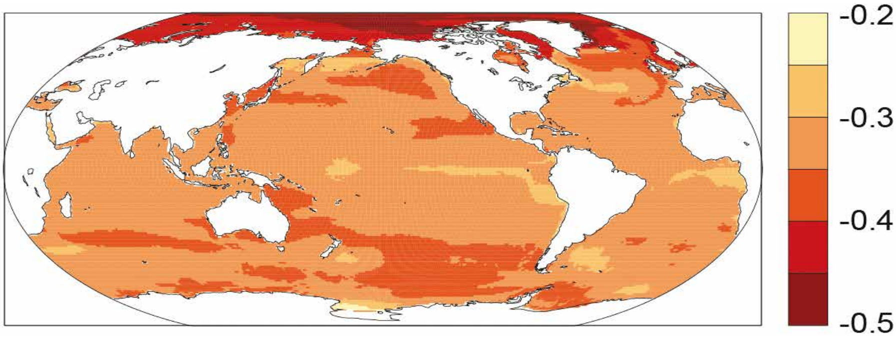
FIGURE 2. **Coastal sites where anthropogenic nutrients have exacerbated or caused $O_2$ declines to <2 mg/litre (<63 µmol/litre) (red dots), as well as ocean oxygen minimum zones at 300 m of depth (blue shaded regions)**




*Source:* Breitburg *et al.*, 2018

Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity. As atmospheric $CO_2$ concentrations increase, the oceans absorb more $CO_2$. This causes a decrease in water pH and in the saturation state of mineral forms of calcium carbonate (CaCO3), which are important for all shell-forming aquatic life (Pörtner *et al.*, 2014). Since the beginning of the industrial era the pH of ocean surface water has decreased by an average of 0.1, corresponding to a 26 percent increase in acidity (IPCC, 2014; Jewett and Romanou, 2017). Variability in ocean acidity is however high in coastal zones, especially in areas with higher freshwater inputs due to lower buffer capacity. Observed trends in global ocean pH already exceed the range in natural seasonal variability over most of the oceans (Henson *et al.*, 2017), and are expected to exceed it further in coming years (Gattuso *et al.*, 2015) with the projected increases in GHG emissions (**Figure 3**).

FIGURE 3. **Median model's change in surface pH from 1850 to 2100 resulting from projected changes in ocean acidification of 11 Coupled Model Intercomparison Project Phase 5 (CMIP5) Earth System Models under RCP8.5**




*Source:* Ciais *et al.*, 2013

Primary production forecasts are highly uncertain for both marine and freshwater systems, because primary production is an integrator of changes in light, temperature and nutrients. However, in the oceans it is expected to decrease by three to nine percent by 2100, with more variable outcomes for freshwater systems, depending on the area.

### Sea level rise

In the recent past, sea level has increased by an average of 3.1 mm/year as a result of climatic and non-climatic factors (Dangendorf *et al.*, 2017). The rate of increase shows a high variability across regions, with values up to three times the global average in the Western Pacific or null or negative values in the Eastern Pacific. Sea level has already risen by a global mean of 0.19 m over the period 1901 to 2010. It is estimated that between 2000 and 2100, the projected global mean sea level rise will very likely (90 percent probability) reach between 0.5 m and 1.2 m under RCP 8.5, 0.4 m to 0.9 m under RCP 4.5, and 0.3 m to 0.8 m under RCP 2.6 (Kopp *et al.*, 2014). There is a high certainty that the sea level will rise in 95 percent of the ocean area; however, there will be significant regional heterogeneity in the sea level rise and thus in its consequences (IPCC, 2014).

### Ocean circulation

Ocean circulation redistributes heat and freshwater across the globe, influencing local climates. A significant part of this redistribution is done by the meridional overturning circulation (MOC), responsible for much of the ocean's capacity to carry excess heat from the tropics to middle and high latitudes, and for the ocean's sequestration of carbon. While the timing of changes is still under debate, partially because of its observed short-term variability (Cunningham *et al.*, 2007), it appears clear that the Atlantic meridional overturning circulation (AMOC) is progressively weakening, resulting in a cooling of sea surface temperature (SST) in the subpolar Atlantic Ocean and a warming and northward shift of the Gulf Stream (Caesar *et al.*, 2018; Thornalley *et al.*, 2018). There is currently much debate about the influence of climate change on ocean circulation. One relevant case is the impact on coastal upwelling (**Box 1**).

## Observed and predicted impacts on inland waters

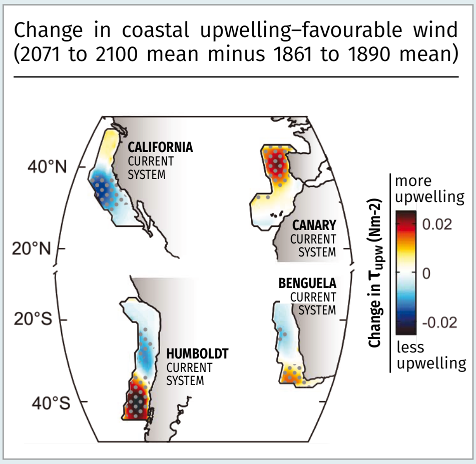
The warming of the climate has significant implications for the hydrological cycle. Changing precipitation, temperature and climatic patterns and the melting of snow and ice affect the quantity, quality and seasonality of water resources. Climate change is already causing permafrost warming and thawing in high-latitude regions, and in high-elevation regions it is driving glacier shrinkage, with consequences for downstream water resources. Observed precipitation changes since 1901 vary across regions. However, models indicate that zonal mean precipitation is very likely to increase in high latitudes and near the equator, and decrease in the subtropics (Ren *et al.*, 2013). The frequency and intensity of heavy precipitation events over land are also likely to increase in the near term, although this trend will not be apparent in all regions because of natural variability.

Droughts are expected to be longer and more frequent in California, the Mediterranean basin, as well as in existing arid zones, leading to reduction in river flows. Although global river discharges have not demonstrated changes that can be associated with global warming during the twentieth century, this is not an indication that climate change has no impact. Discharge, connectivity and flow in most large river systems have been considerably impacted by human influences such as dam construction, water abstraction

## Box 1. Coastal upwelling

Major coastal upwelling zones exist along the edges of eastern boundary currents of the Pacific (Humboldt Current and California Current) and Atlantic Oceans (Canary Current and Benguela Current). In these eastern boundary upwelling systems (EBUS), prevailing winds interact with coastal topology and the earth's rotation to push surface waters offshore. These waters are then replaced with nutrient-rich deep waters (upwelled), making EBUS some of the most productive of the world's marine ecosystems. There is already evidence of the complex relationship between climate change and coastal upwelling, not just in terms of changes in upwelling strength, but also the timing and the geographical variability of upwelling processes (Bakun *et al.*, 2015; Sydeman *et al.*, 2014; Xiu *et al.*, 2018). Coastal upwelling processes are poorly represented in the global climate models, which means their projections do not take into account possible future changes in coastal upwelling and associated processes. This remains one of the larger sources of uncertainty in our knowledge of the impacts of climate change on global fisheries (**Figure 4**).

FIGURE 4. **Illustration of upwelling intensification hypothesis. Change in coastal upwelling favourable winds ($\tau_{upw}$) between two periods: 2071 to 2100 average minus 1861 to 1890 average**




*Source:* Rykaczewski *et al.*, 2015

and regulation. This limits the conclusive evidence of climate change impacts on rivers.

Despite uncertainties, it is expected that the contribution of snowmelt to river flows will increase in the near future (Jha *et al.*, 2006; Siderius *et al.*, 2013; Pervez and Henebry, 2015).

Freshwater species are particularly sensitive to temperature changes and water temperatures are expected to increase in most freshwater systems, as a result of an increase of air temperature. This is linked to the relatively shallow nature of surface freshwaters and their susceptibility to atmospheric temperature change. There is a high confidence that rising water temperatures will lead to shifts in freshwater species' distributions and exacerbate existing problems with water quality, especially in those systems experiencing high anthropogenic loading of nutrients (IPCC, 2014).

## Climatic variability superimposed to climate change

The interactions and overlap between anthropogenic climate change and natural climatic variability can have pronounced effects that may be difficult to disentangle. One of the best known example is that of El Niño Southern Oscillation (ENSO) cycles that have challenged scientists for decades (**Box 2**).

Since the publication of the IPCC AR5, there have been a number of modelling studies that have shown an increasing frequency of extreme El Niño events as a result of climate change (e.g. Cai *et al.*, 2014, 2015). It is significant, in this context, that the 1982/1983, 1997/1998 and most recent 2015/2016 El Niño events were not just the most intense in the modern observational record but also the most peculiar, exhibiting unusual characteristics distinct from any other observed events (Santoso *et al.*, 2017).

### Box 2. El Niño Southern Oscillation

ENSO is the interaction between the atmosphere and ocean in the tropical Pacific that results in three- to seven-year periodic oscillations in the temperature of surface waters of the equatorial Pacific, between particularly warm and cold temperatures, referred to as El Niño and La Niña, respectively. The release of heat from the ocean to the atmosphere during El Niño events is known to cause changes in global atmospheric circulation, cyclone and hurricane patterns, monsoons, and heat and precipitation patterns, with associated drought and flooding episodes (Reid, 2016). The effects are felt worldwide, with consequences for marine and freshwater systems throughout the food web, including species sustaining fisheries. In some cases there are noticeable increases in fish catches, in other cases new species appear, which fishers are not sufficiently prepared to catch, etc. In other ecosystems El Niño means drought, increased temperatures and a greater frequency of harmful algal blooms (HABs). In many inland ecosystems El Niño means insufficient water for fisheries and aquaculture. Even though it is still under debate, it is likely that El Niño may be affected by anthropogenic climate change.

# 4 Why is climate change particularly relevant for fisheries and aquaculture?

The scenarios and impacts described above will affect, and in many cases are already affecting, millions of people that depend on fisheries and aquaculture for both food and livelihoods. Thus, the Technical Paper presents available information worldwide on the implications for fisheries and aquaculture, paying special attention to those elements and situations where food security and livelihoods are threatened.

## Applying a poverty lens

Approximately 11 percent of the global population, or about 767 million people, live in extreme poverty, and 815 million go hungry every day (FAO *et al.*, 2017). Many of these people can be found in small-scale fishing and fish farming communities where they are commonly marginalized politically, economically and socially, even in countries with a generally good status in human development.

**Chapter 2** focuses on the relationship between climate change, poverty and vulnerability. The chapter emphasizes that the impacts of climate change on fisheries and aquaculture will affect individuals and communities that depend on the sector for their livelihoods, and thus contends that efforts to adapt to and mitigate climate change must be human-centred.

**Strategies for adaptation to climate change should emphasize the need for poverty eradication and food security, in accordance with relevant international agreements, including the Paris Climate Agreement.**

A key message coming from **Chapter 2**, and elsewhere in the Technical Paper, is that small-scale fishers and fish farmers are especially vulnerable to climate change because of both their geographical locations and their economic status. The latter means that a crucial part of increasing the resilience of these individuals and communities must be to eradicate poverty and provide food security for them, as emphasized by the Paris Climate Agreement, the United Nations Agenda 2030 and other international agreements. Achieving this requires that adaptation to climate change should be multidimensional and multi-sectoral. Strategies should allow for flexibility in practices and opportunities for those impacted by climate change and ensure that they have opportunities for diverse livelihoods, allowing them to respond to the changes.

Strategies and measures need to address any imbalances in power amongst stakeholders and stakeholder groups as well as inequities in, for example, gender, market access, tenure rights and others.

**Active support for adaptation is required at national, regional and local levels of governance and a stronger emphasis should be placed on the contribution of fisheries and aquaculture to poverty reduction and food security in countries' Nationally Determined Contributions (NDCs).**

## Current supply and demand for fishery and aquaculture products and future evolution

In recent decades, there has been a major expansion in production, trade and consumption of fishery and aquaculture products, although the rate of expansion has slowed down in recent years, and shifted from capture to culture sectors (**Chapter 3**). Fish is an important source of protein in many countries, especially small island developing states (SIDS) and some landlocked or coastal countries in Africa and Asia, where it can contribute 50 percent or more of animal protein in diets. Furthermore, fish and fishery products are important sources of nutrients and micronutrients, including vitamins, several minerals and omega-3 fatty acids.

Globally, an estimated 36 percent of total fish production is exported, making fish and fishery products among the most traded food commodities (FAO, 2018). This means that the sector can be considered globalized but, especially in the case of inland fisheries and aquaculture, production tends to be concentrated in certain countries and regions. Developing countries, in particular in Asia, have a growing share of production and trade, increasing from 21 percent in 1950 to 70 percent in 2015, with a significant contribution coming from small-scale and artisanal fishers and fish farmers. These facts highlight the shifting nature of the fisheries and aquaculture sector in recent decades, both in terms of the geographical distribution and the contribution of each industry to global production.

**Climate change is expected to lead to changes in the availability and trade of products from fisheries and aquaculture, with potentially important geopolitical and economic consequences, as well as for food security, especially for those countries most dependent on the sector for food and livelihoods.**

Exacerbating these climate-driven impacts, human population growth is likely to increase demand, and potentially increase prices in the coming decades. While price increases may lead to a decrease in fish consumption globally, higher prices should provide an incentive for those engaged in fisheries and aquaculture to increase their production, and efficiency.

# 5 Climate change impacts on marine capture fisheries

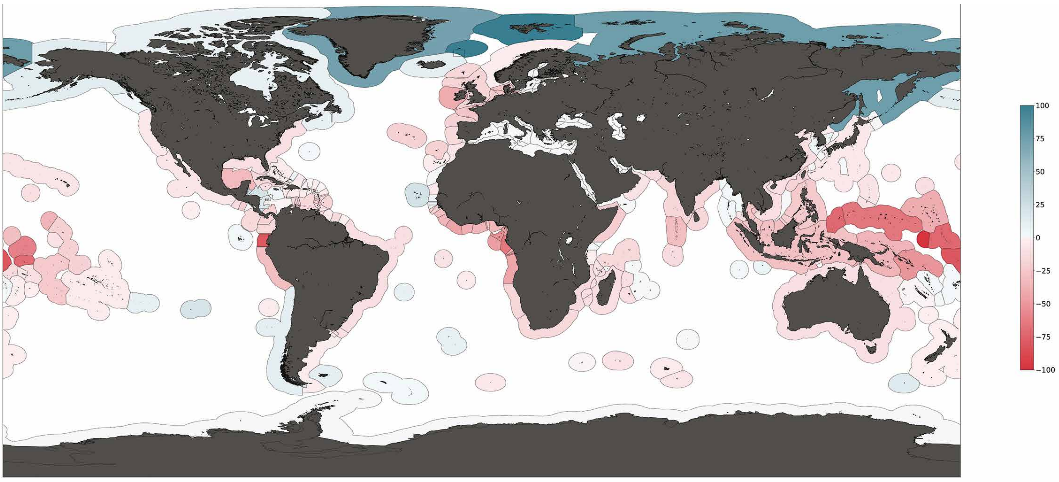
**Chapter 4** of the Technical Paper provides projections of the changes in marine maximum catch potential between now and the end of the twenty-first century. The projections are derived from two models, selected because they are characterized by a significantly different way of modelling ecological processes. Both of the models are driven by the same outputs from collections of earth system models from the fifth phase of the Coupled Model Intercomparison Project (CMIP5), and are thus comparable. Projections were made under the lowest (RCPs 2.6) and highest (RCP8.5) emission scenarios (see **Chapter 1**).

**Application of these two models resulted in projections indicating that the total maximum catch potential in the world's exclusive economic zones (EEZs) is likely to decrease by 2.8 to 5.3 percent by 2050 (relative to 2000) under RCP2.6, and by 7.0 to 12.1 percent under RCP8.5.**

Extending these projections, the projected decrease does not change much by 2095 under RCP2.6 but is forecast to be considerably greater, at 16.2 to 25.2 percent, by 2095 under RCP8.5 (**Figure 5**). These projected decreases, with the exception of the latter, may not seem particularly large at the global level but the projected changes showed substantial variation across regions and the impacts could be much greater for some regions.

**The biggest decreases in catch potential can be expected in the EEZs of countries in the tropics, mostly in the South Pacific regions, as also noted elsewhere (Barange *et al.*, 2014;**

FIGURE 5. **Projected changes in maximum catch potential (%) under RCP8.5 by 2050 (2046 to 2055) for the Dynamic Bioclimate Envelope Model (DBEM) projections**

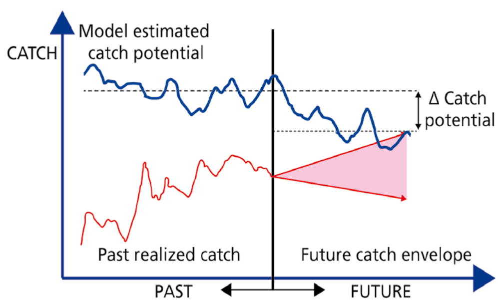



**Blanchard *et al.*, 2014; Cheung *et al.*, 2010). The catch potential in the temperate Northeast Atlantic is also projected to decrease between now and the 2050s. For the high-latitude regions, catch potential is projected to increase, or show less of a decrease than in the tropics, but there was much higher variability between the two models, time periods and the EEZs in the projected maximum catch potential in these high-latitude regions than those from low latitudes.**

An important consideration is that the above projections are not reflecting potential changes from current catch levels, but rather changes in the capacity of the oceans to produce fish in the future compared to their current capacity. Fish catches reflect the productive capacity of the ocean, as well as the management decisions taken in response to this productive capacity. For example, future catches in an area where the productive capacity is expected to decline may actually increase if management measures restore currently over-exploited stocks (see also Brander *et al.*, 2018). Alternatively, higher future catches in an area where potential production is expected to increase may not be realized if management measures are not properly implemented (**Figure 6**).

**The interactions between ecosystem changes and management responses are crucial to determine future directions of change, to minimize the threats and maximize the opportunities emerging from climate change.**

FIGURE 6. **Conceptual diagram illustrating the relationship between estimated catch potential, and its change over time driven by climate considerations and realized catch**



# 6 Regional analysis of climate change impacts, vulnerabilities and adaptations in marine capture fisheries

## Observed and predicted impacts across marine regions

**Chapters 5 to 17** present case studies on the implications of climate change for marine capture fisheries from many regions of the world, to complement the model results. Collectively they provide unequivocal evidence of the significant impacts that climate change has already had on marine fisheries in some regions and the need to take steps to adapt to current (in many regions) and future (in all regions) climate change. They also provide valuable examples of how different countries are already responding in order to minimize the negative impacts on a sector that provides vital social and economic benefits for many countries.

The observed impacts of climate change reported in these case studies are broadly consistent with the expectations arising from global projections such as those provided in **Chapter 4**. Warming in ocean temperatures is reported in most regions of the world and has been arguably most obvious in higher latitudes (see also **Chapter 1**). In the North Atlantic as a whole (**Chapter 5**), SST increased at a rate of 0.1 °C to 0.5 °C per decade over the past century, with particularly rapid warming since the 1980s, while temperatures across the North Pacific increased by 0.1 °C/yr to 0.3 °C/ yr from 1950 to 2009.

As would be expected, given their size and oceanographic complexity, changes in both these regions showed considerable spatial diversity. At the opposite end of the globe, in the Southern Ocean, the picture is not as clear and, while there have been some examples of warming and reductions in sea ice in this region, the South Pole has undergone cooling in recent decades, probably related to a low-pressure system that is associated with the ozone hole, and annual sea ice cover in the Antarctic has increased over the past two or three decades (**Chapter 17**). In the mid-latitudes, the southeast and southwest coasts of Australia are reported as having experienced a 2 °C increase in temperatures over the last 80 years (**Chapter 16**) and over the last 30 years, SST in the Southwest Atlantic warmed at an average of between 0.2 °C and 0.4 °C per decade (**Chapter 15**).

Changes in the major upwelling regions are more complex. The Humboldt Current system has been cooling from the early nineteenth century to the present, in association with more intense upwelling, while those areas of the Benguela Current ecosystem that are dominated by upwelling have shown different trends: SST has increased by between 0.2 °C and 0.5 °C per decade over the past three decades in the northern parts of the Namibian EEZ, the central regions around Walvis Bay have shown no meaningful change, while the southern Benguela has cooled over the last four decades, possibly as a result of stronger wind-driven upwelling (**Chapter 11**).

**The complex relationship between climate change and coastal upwelling, not just in terms of changes in upwelling strength,**

**but also the timing and the geographical variability of upwelling processes (Bakun *et al.*, 2015; Sydeman *et al.*, 2014; Xiu *et al.*, 2018), remains highly uncertain, with implications for some of the most productive marine fisheries (Chapter 1).**

Notably, coastal upwelling is poorly represented in the global climate models used to drive the ecosystem models described in **Chapter 4**, which means their projections do not take into account changes in coastal upwelling and associated processes. This remains one of the larger sources of uncertainty in our knowledge of the impacts of climate change on global fisheries. Turning to the lower latitudes, warming has been taking place in the Western Indian Ocean at a comparatively rapid rate over the last 100 years or so, and SST increased by an estimated 0.6 °C between 1950 and 2009, with some spatial variability (**Chapter 12**). **Chapter 13** reported an increase in SST of 0.2 °C to 0.3 °C over the previous 45 years along the coast of India. In the Western Central Pacific, SST increased by more than 0.7 °C between 1900 and the early twenty-first century, while differing trends were reported for the Northeast Tropical Pacific. Trends have shown similar diversity across the Western Central Atlantic region (**Chapter 9**) ranging from warming on the North Brazil shelf to cooling along the southeastern shelf of the United States of America.

The projected changes in ocean temperatures again differ across the regions and show spatial trends that are broadly compatible with the global forecasts reported in **Chapter 4**. For example, in the Northwest Atlantic under RCP8.5, a scenario of long-term high energy demand and high GHG emissions in the absence of climate change policies, SST is forecast to rise a further 2.0 °C to 4.0 °C by 2100, accompanied by increasing incidence of storms and sea level rise, while temperatures are expected to rise in the North Pacific by between 3.0 °C and 3.2 °C between the end of last century and 2050 to 2099 under the same RCP scenario, or by 1.4 °C to 2.2 °C under a more moderate emissions scenario. The Arctic Pacific is expected also to experience warming but at a slower rate than further south. Some other examples are: an increase of less than 1 °C by 2100 relative to 2000 to 2010 for the Western Central Pacific under RCP2.6 or by 2.5 °C to 3.5 °C under RCP8.5; warming of between 1 °C and 2.0 °C (depending on locality) in the oceans around Australia over the next 100 years under RCP2.6, or between 2 °C and 5.0 °C under RCP8.5. In the Mediterranean, estimates of future increases in SST range from 1.73 °C to 2.97 °C by the end of this century in comparison to those experienced in the second half of last century, and the Black Sea is also projected to warm by 2.81 °C and 0.51 °C for summer and winter respectively by 2100. The rates vary, but temperatures are changing, in most cases warming, and will continue to do so for the remainder of this century.

The wider ramifications of climate change are also well described in the chapters on the different marine regions and show a common theme of change, albeit with considerable regional diversity. The interactions between warming oceans, increased stratification and their implications of reduced dissolved oxygen concentrations are referred to for several regions including the Eastern (**Chapter 8**) and Western Central Atlantic (**Chapter 9**) regions, Northeast Tropical Pacific (**Chapter 10**), Western Indian Ocean (**Chapter 12**), and Southwest Atlantic (**Chapter 15**). At the same time, upwelling is reported to be strengthening in the Canary Current (Eastern Central Atlantic) and, under the RCP8.5 scenario, is projected to continue to do so until the end of the century (**Chapter 8**), which is consistent with information in **Chapter 6** that there is evidence that wind strength could be increasing in some of the bigger coastal upwelling systems, but the implications of that for future stratification remain unclear.

Striking decreases in the pH of the North Atlantic (about 0.0035 pH units per year for the last 30 years) are highlighted as a key message for **Chapter 5**, together with forecast ongoing declines that raise concerns about the potential impact on harvested shellfish and early life stages of some finfish species. Declining pH is also referred to in **Chapter 12** on the Western Indian Ocean, **Chapter 16** on Australia, and others. Projections for the Western Central Atlantic (**Chapter 9**) and Western and Central Pacific (**Chapter 14**) indicate that, depending on how much the concentration of $CO_2$ in the atmosphere increases, aragonite saturation values (Ωar) could possibly fall below 3.0 (extremely marginal), which would likely lead to net erosion of the coral reefs in these areas.

**While there is certainty in the direction and magnitude of ocean pH decline, and of its largely negative impacts on marine organisms (Kroeker, Kordas and Harley, 2017), most projection models do not incorporate the potential impacts of ocean acidification (OA) on fish and fisheries. This is because we lack sufficient understanding of the capacity for marine organisms to adapt through acclimation, transgenerational and evolutionary adaptation (Gaylord *et al.*, 2015; Munday *et al.*, 2013; Munday, 2014), to reliably predict OA impacts on marine populations and ecosystems.**

Sea level rise is another phenomenon driven by global warming that is being experienced in many regions, albeit at different rates. **Chapter 13** reports that two-thirds of Bangladesh lies less than five metres above sea level and, with projected sea level rise, saline water could penetrate 50 km further inland than at present, with serious consequences for the country. Similar risks are reported for coastal areas in the Eastern Central Atlantic (**Chapter 8**). The mean sea level in the Western Central Atlantic could rise by between 0.35 to 0.65 m by the end of this century depending on the extent of future GHG emissions. In the Mediterranean projections indicate a likely continuation in the recently observed rate of between 2 mm/yr and 10 mm/yr.

## Effects on ecosystems and fisheries

**Chapters 5 to 17** present a comprehensive view of the impacts of climate change on marine ecosystems and fisheries and a complex picture of potential future trends. A few examples are presented here to illustrate what is occurring and could take place in the future.

**At the ecosystem level, common impacts emphasized in the different regions are shifts in the distribution of fish species and other taxonomic groups, increasing incidences of coral bleaching with serious implications for affected ecosystems, and increasing frequency of outbreaks of HABs.**

Serious incidences of bleaching of coral reefs are reported from, for example, the Western Central Atlantic (**Chapter 9**), Western Indian Ocean (**Chapter 12**), Western and Central Pacific (**Chapter 14**) and Australia (**Chapter 16**). Increasing frequency and intensity of such events is expected to lead to substantial reductions in the extent of live coral cover, and could lead to a loss of coral reef species, changes in the dominant species assemblages and, in some cases, a complete phase shift to algal dominated reef communities. These changes will lead to significantly altered ecosystem services (**Chapters 9 and 14**). The forecast increases in acidification could exacerbate this problem, at least in some regions. There are several examples of increasing frequencies in the incidence of


HABs. For example, **Chapter 13** reports more frequent incidence, greater intensity and wider areas of occurrence of HABs in the Arabian Sea and the Bay of Bengal, while the incidence may also be increasing in the coastal waters of South Africa (**Chapter 11**) and the Western Central Atlantic (**Chapter 9**). HABs are often associated with mortality of fish and give rise to food safety concerns for humans.

Shifts in the distribution of species of fish of importance to fisheries are one of the most widely recognized and acknowledged impacts of climate change on the oceans. All the marine chapters make references to such shifts but those that have taken place in the North Atlantic are arguably the best known and studied case. **Chapter 5** describes the profound changes in the distribution and production of fish species that have been observed in both the Northeast and Northwest Atlantic, which have had important impacts on fisheries and their management in the region. This trend is expected to continue and changes in the distribution and production of species is forecast to lead to substantially increased yields in high-latitudes but decreased yields in areas south of about 50 °N. Two other regional examples that perhaps justify singling out in this summary, because of both the extent of the shifts and the extent to which they have been monitored, are the changes in distribution in the oceans of Western Australia (**Chapter 16**) and those that have and are occurring in the Mediterranean (**Chapter 7**).

The research on the distribution and likely impacts of climate change on future distribution of tuna, and the implications for fisheries management, also warrants highlighting in both the Western and Central Pacific (**Chapter 14**) and Western Indian Ocean (**Chapter 12**), particularly for some SIDS.

**Climate change has already caused noticeable shifts in the distribution and abundance of highly-distributed fish species, such as tunas, and substantial future changes can be expected under a warming climate, with important impacts on national incomes of dependent countries and for the harvest strategies currently being used for their management.**

The most important adaptations recommended to address these changes are somewhat different in the two regions but involve actions aimed at ensuring, as far as possible, that the current social and economic benefits obtained from these fisheries across the value chain are maintained. The chapters in the Technical Paper did not examine the impacts of climate change on tunas in the Atlantic but, as would be expected from the results for the Pacific and Indian oceans, tunas in the Atlantic have also been reported to have shown significant shifts in distribution in recent decades (Monllor-Hurtado, Pennino and Sanchez-Lizaso, 2017) and climate change is expected to lead to changes in the spatial and population dynamics of the species group in the future (Muhling *et al*., 2015).

# 7 Climate change impacts, vulnerabilities and adaptation in inland capture fisheries

Predictions of the impacts of climate change on inland fisheries are particularly difficult, because in addition to direct impacts inland fisheries are indirectly affected by the impacts of climate change in other sectors, which places inland fisheries in competition with other users of the resource base: water. The inclusion of biological, ecological and human responses in models greatly increases their complexity, which in turn reduces predictive power. The prediction of inland fishery responses to climate change is therefore extremely challenging.

Freshwater is a crucial commodity used in or affected by many sectors of human life, ranging from human consumption to agriculture, recreation and others. As a result, the world's limited resources of freshwater are subjected to many anthropogenic pressures including abstraction, river regulation, damming, pollution, habitat degradation, fishing and others.

**The already high demand for water is expected to increase in the future as a result of human population growth and development, which, unless urgent remedial action is taken, will have serious negative impacts on inland fisheries and the benefits they provide. Unfortunately, in the competition for this scarce resource the valuable contributions of inland fisheries are frequently not recognized or are under-valued and priority is given to other more visible demands for water, with serious consequences for the sustainability of inland fisheries.**

As an additional stressor, climate has a strong controlling influence on the physical, chemical and biological processes in freshwater ecosystems, which leads to changes in distribution, abundance and production of inland fishery resources. Climate change is also changing the global hydrological cycle, through changes in precipitation and evaporation (Settele *et al.*, 2014). Overall, climate change is driving changes in the composition of species assemblages, the abundance, biomass and distribution of species, fish yields and the efficiency of fishing methods and gears (**Figure 7**).

Chapter 18 analysed a set of river basins on all continents and found that an increase of up to 1.8 °C in water temperature is expected, with geographical heterogeneities, including areas where the increase is expected to be minor, such as in the Lower Mekong River basin.

Chapter 19 explores the likely future impact of these climate-induced changes, in combination with other stressors including population growth, demand for freshwater from other sectors, construction of dams and others, for 149 countries with inland fisheries.

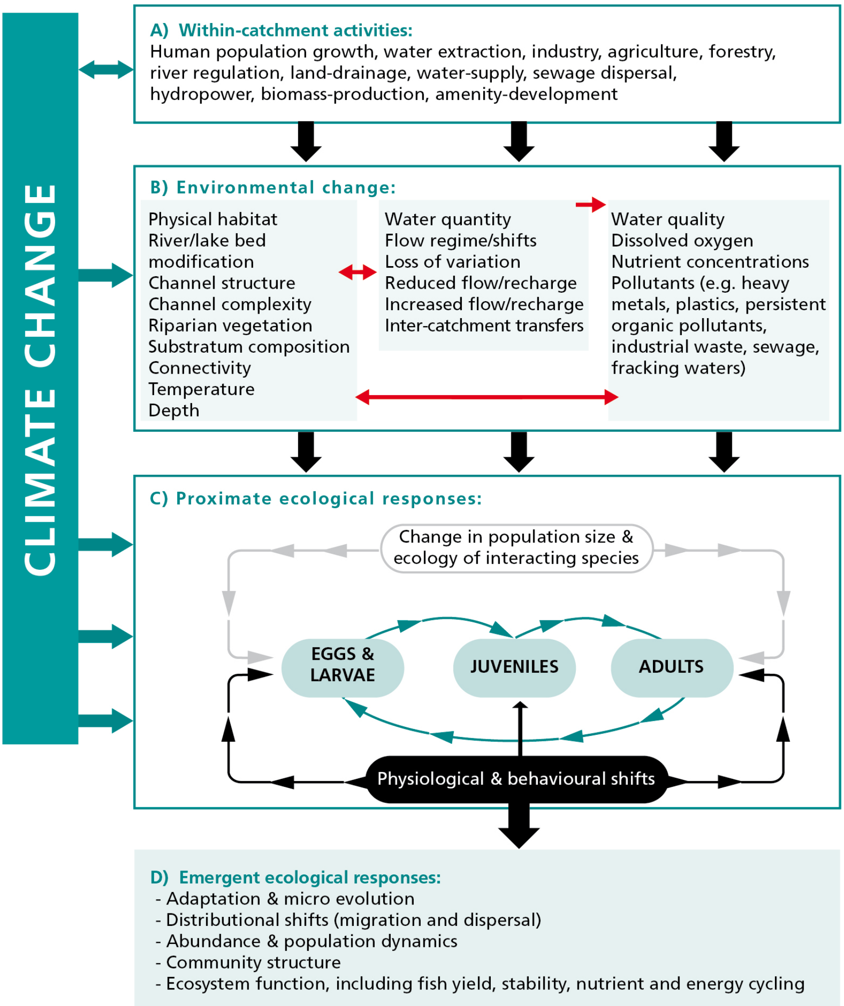
**The results indicated a wide range in magnitude of current and future stressors, extending from eight countries that are currently facing high stresses that are projected to become even higher in the future (including for example, Pakistan, Iraq, Morocco and Spain) and, at the opposite end of the range, 17 countries that were found to be under low stress at present and are projected to**

**remain under low stress in the future (including for example, Myanmar, Cambodia, the Congo, the Central African Republic and Colombia).**

The remaining 124 countries fell within these two extremes, of which the largest group, 60 countries currently accounting for 46.9 percent of the global inland fishery catch, were found to be facing medium stress now, and this is expected to continue in the future.

The results indicated that the category of stress is expected to increase by a grade (e.g. medium to high) in 59 countries that currently account for 36.4 percent of the global catch. Thirty-nine countries, accounting for 26.3

FIGURE 7. **Diagram of climate change potential effects on freshwater fisheries through its influence across a range of factors, from catchment-level activities, habitat characteristics, and responses of individual fish, which together affect fish yield and other measures of ecosystem function.**




*Source:* Adapted with permission from Harley et al. (2006) © 2006 Blackwell Publishing Ltd/CNRS, and Milner (2016) © 2016 by John Wiley & Sons, Ltd percent of the current catch, are forecast to experience high or very high stress in the future, compared to 14 countries at present accounting for only 1.8 percent of the global catch.

Chapters 18, 19 and 26 explore the impacts of climate change on inland fisheries. Inland capture fisheries make important contributions to livelihoods and economies around the world, generating recorded catches of over 11 million tonnes in 2015, equivalent to just over 12 percent of total production from marine and freshwater capture fisheries. They provide high quality, affordable food to some of the most poor and vulnerable people in the world and are a source of employment and livelihoods for tens of millions of people, as well as being a foundation of cultural systems in many places (Chapters 3 and 18).

The case studies described in **Chapter 19** present a mixed picture of current and future impacts.

**In all these cases, non-climate stressors are considered to be more serious threats to the inland fisheries of these regions than climate stressors.**

For example, in the Yangtze River basin, over-exploitation, habitat degradation and pollution are thought the be main threats to the future of inland fisheries, while the large variability in precipitation, the already dense population and the rapidly developing economy mean that the basin is highly vulnerable to climate change. In the Ganges River basin, the increasing human population and difficulty in maintaining ecological flows in the river because of increased water demand is expected to be the primary factor impacting inland fisheries. The picture emerging from the other cases examined in **Chapter 19** is similar, highlighting threats such as changes in the size, duration and timing of flow events, economic development, agricultural development, deforestation and increasing modification of river floodplain habitats, all of which will have serious impacts on these inland water bodies and systems and their fisheries.

In most inland fisheries climate change will be an addition to already heavily stressed systems, but there will be large variability in its effects. For example, in Finland, climate-driven temperature increases are likely to result in higher productivity of the fisheries but with large changes in dominant species and other fishery attributes. In the Lower Mekong River basin however, climate change is expected to affect air and water temperatures and precipitation, the volume and flow of the river and the agricultural practices that will collectively impact the resources supporting this globally large collection of fisheries.

Observed and projected climate impacts in other case studies included increasing water temperatures leading to changes in fish species, potentially from higher to lower value species, changes in precipitation (as rain or snow) and consequently water flows, and more frequent and intense extreme events such as floods. In some cases, (e.g. La Plata River basin) the increasing precipitation and run-off could extend and improve connectivity between fish habitats, while decreased precipitation and more extreme events will negatively impact flows and habitats in others (e.g. the Amazon River Basin).

**The implications of the changes for individuals, communities and countries will depend on their exposure, sensitivity and adaptive capacity but in general can be expected to be profound. Their ability to adapt to them will be determined by a range of factors including, for example, the extent of their dependence on the activity, the wealth and assets they possess, their education, location and other factors (Chapter 18; Aswani *et al.*, 2018; Williams and Rota, 2011).**


In their favour is that the uncertainty and variability that have always characterized inland fisheries means that the fishers and other stakeholders are accustomed to the need for adaptation. They have developed strategies which assist adaptation, such as changing exploitation rates, altering their fishing operations, migrating and having diverse livelihoods. Nevertheless, the poverty and food insecurity of many of them seriously constrains this ability and for many, the future impacts of climate change, coupled with increasing pressure from multiple other anthropogenic pressures, are likely to exceed their existing adaptive capacity unless far-reaching action is taken to increase it. The adaptation options of the past are becoming increasingly limited.

As reported above, an overriding theme in inland fisheries globally is that they are susceptible to the activities and impacts of other sectors and that these impacts are generally of greater concern than the direct effects of climate change *per se*. These other sectors are also being impacted by climate change and their efforts to adapt or mitigate their contributions to climate change may result in further impacts, primarily negative, on inland fisheries.

Therefore, it is critical for ensuring the resilience and sustainability of inland fisheries that adverse impacts from other sectors are minimized, particularly in terms of water. This requires, in particular, taking steps to ensure adequate environmental flows and the maintenance of the habitats that sustain ecosystems and the fisheries that depend on them. An important requirement is that the role and goals of inland fisheries must be adequately addressed in catchment, basin and regional management plans that involve or have implications for water supplies and systems. This implies the need to develop and implement integrated, holistic approaches at appropriate scales, and that address the range of ecosystem services, including support of inland fisheries. They also need to encompass water and environmental integrity, environmental rehabilitation, wetland management, water storage and quality and carbon sequestration. For transboundary basins and systems, such holistic plans should be incorporated in the relevant regional and international agreements.

# 8 Vulnerabilities and responses in fisheries

**The impacts of climate change are expected to be heaviest for small-scale fishers in several regions, but there are also possibilities that changes in distribution could create new opportunities for them (e.g. Chapters 7, 10 and 15).**

In the Northeast Tropical Pacific (**Chapter 10**) small-scale fishers have some advantages because they are able to adapt quickly to take advantage of available resources, but as many of the species they typically harvest are considered to be vulnerable to habitat degradation, their new opportunities may be limited. Similar considerations probably apply to the small-scale sector in most regions. Small-scale fishers are also considered to be among the most vulnerable groups in the Southeast Atlantic, Southwest Indian Ocean and Western and Central Pacific. In the Mediterranean and Black Sea, the developing countries in the south and southeast of the region are considered to experience greater exposure to the changes and to have lower adaptive capacity to cope with them and therefore to be more vulnerable to climate change. These examples all highlight the importance of adaptive capacity, or limitations in adaptive capacity, as a key driver of vulnerability.

**A further important conclusion coming from a number of chapters, and including the tuna examples, is that the expected changes in distribution are likely to cause new, or exacerbate existing conflicts between users, both within countries and when the distribution of important species changes across boundaries between neighbouring countries or between countries and the high seas.**

Where fish resources are shared or straddle international boundaries, changes in distribution could lead to disagreement about allocations, as occurred when North Sea mackerel distribution shifted northwards and westwards, decreasing in abundance in Norwegian waters and increasing in the waters of Iceland and the Faroe Islands. This led to a dispute over allocations between the affected nations (Jensen *et al.*, 2015) that resulted in the scientific recommendations for the total allowable catch being exceeded for a number of years (**Chapter 5**), and serves as a good example of the need for flexibility in management and allocation arrangements, both national and international, to enable rapid, responsible approaches to such changes.

In addressing climate change, it is essential to recognize that, almost invariably, climate change is not the only threat or stressor on a fisheries system but is an additional, possibly unidirectional one, adding to what is typically a range of other stressors and uncertainties from anthropogenic and natural causes. These can include, for example, overfishing, pollution, habitat loss, competition for space and environmental variability.

**Adaptation to climate change must be undertaken within that multi-faceted context and any additional measures or actions taken in response to climate change should complement and strengthen overall governance and sustainable use.**

This principle is widely recognized in the marine regions and fisheries addressed in **Chapters 5 to 17**, and there is frequent reference to efforts to ensure effective management of the fisheries and to reduce the impacts from other stressors. These include implementation of the FAO Code of Conduct for Responsible Fisheries and related instruments, ecosystem approaches to fisheries, spatial planning including effective systems of marine protected areas, ensuring participatory systems of governance and strengthening control and enforcement in the fisheries sector. The additional uncertainty arising from climate change reinforces the importance of adaptive approaches to management that include monitoring of conditions and performance of the fishery, with feedback to management decisions and actions. This enables adjustment, or adaptation, to accommodate any important changes in the system and ensure performance is maintained in relation to agreed objectives (which may also need to be adjusted, within the bounds of sustainability, if changed conditions require it).

Examples of the action that will be required to facilitate and support adaptation are provided in Chapters 18, 19 and 26.

**Adaptive management within the framework of an ecosystem approach to fisheries is essential for maintaining, and restoring, resilience of ecosystems and species to the coming changes. This must be done with the engagement of stakeholders and in a participatory manner. Some of the impacts of climate change are certainly likely to be positive.**

For example, increased precipitation could reduce current water stress in some regions and also lead to the expansion of habitats available to fish, leading to higher abundance and potential yields. Taking advantage of new opportunities could require investment in infrastructure and equipment, for which external support may be required. In cases of both new opportunities and negative impacts, a key requirement for nearly all countries and regions will be to ensure flexibility (within the limits of sustainable use) in policies, laws and regulations that will allow fishers to switch between target species and adjust their fishing practices in response to changes in the ecosystems they utilize for fishing.

**Adaptation in post-harvest processes will also be important through, for example, the development or improvement of storage and processing equipment and capacity and implementation of robust biosecurity systems in order to ensure the quality of fish and fish products through to the consumers, as well as facilitating possible access to higher value markets.**

As stated above, small-scale and artisanal fisheries and fishers are identified as being particularly vulnerable to the impacts of climate change and a number of the adaptation options referred to in these chapters are aimed primarily at them. They include implementation of the FAO *Voluntary guidelines for securing sustainable small-scale fisheries* (FAO, 2015), and the *Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests* (FAO, 2012) to promote secure tenure rights and equitable access to fisheries as a means of eradicating hunger and poverty and supporting sustainable development. Other specific options include wider use of community-based approaches to fisheries governance, flexibility to enable switching of gears and target species in response to changes, creation of alternative livelihoods, product beneficiation, capacity-building to enhance resilience in different ways, and improving the economic stability of small-scale fishers and those involved in associated activities through, for example, improved access to credit, microfinance, insurance services and investment. Some of these measures require institutional adaptation, whether it is to set new transboundary processes, or to facilitate the changes in primary target species, or to accommodate changes in the timing of processes such as fisheries recruitment.

**Noting the likelihood of increasing incidence of extreme events, measures to improve early warning systems, safety at sea and for protection of fisheries-related infrastructure such as safer harbours, landing sites and markets are also being considered or implemented.**

Finally, a number of the marine fishery chapters referred to the need to reduce the uncertainties associated with climate change and its impacts through improved monitoring and research. In addition to providing valuable information for research into climate change, improved monitoring could be linked in some instances to the establishment of early warning systems to alert fishers and the stakeholders of imminent extreme events, including the incidence of HABs, and also to inform fishers of changes taking place, thereby potentially strengthening their adaptive capacity. Research to support adaptation efforts is also required to facilitate more effective adaptation and to reduce the risk of maladaptation.

# 9 Aquaculture and climate change

Aquaculture is making an increasing contribution to global production of fish, crustaceans and molluscs and thereby to the livelihoods, food security and nutrition of millions of people. By helping to meet the growing demand for these products aquaculture also alleviates the price increases that would otherwise result from any escalating gap between supply and demand. Aquaculture no longer enjoys the high annual growth rates of the 1980s and 1990s but remains the fastest growing global food production system. Average annual growth rate was 5.8 percent during the period 2000 to 2016, although double-digit growth still occurred in a small number of individual countries, particularly in Africa from 2006 to 2010. Overall, between 1950 and 2015 global aquaculture production grew at a mean annual rate of 7.7 percent and by 2016 had reached 80.0 million tonnes of food fish and 30.1 million tonnes of aquatic plants, as well as 37 900 tonnes of non-food products (FAO, 2018), equivalent to 53 percent of global production of fish for food by capture fisheries and aquaculture combined (**Chapter 3**).

Climate change can have direct and indirect impacts on aquaculture, and in the short- and long-term. Some examples of short-term impacts described in **Chapter 20** include losses of production and infrastructure arising from extreme events such as floods, increased risk of diseases, parasites and HABs, and reduced production because of negative impacts on farming conditions. Long-term impacts include reduced availability of wild seed as well as reduced precipitation leading to increasing competition for freshwater. Climate-driven changes in temperature, precipitation, ocean acidification, incidence and extent of hypoxia and sea level rise, amongst others, will have long-term impacts on the aquaculture sector at scales ranging from the organism to the farming system, to national and global.

**It is clear that these changes will potentially have both favourable and unfavourable impacts on aquaculture, but the available information indicates that unfavourable changes are likely to outweigh favourable ones, particularly in developing countries where adaptive capacity is typically weakest.**

The threats of climate change to aquaculture have been recognized by some countries and, as of June 2017, of the 142 countries that had submitted their NDCs, 19 referred to aquaculture or fish farming. Nine of those included a focus on adapting aquaculture to climate change, while ten included proposals to use the development of aquaculture as an adaptation and/or mitigation measure in their efforts to address climate change.

**Chapter 20** also presents a number of case studies of vulnerability assessments, with examples at national level (Chile), local (salmon aquaculture in Chile and South Sulawesi, Indonesia) and at the watershed scale (Mekong watershed). Assessments at national scale provide useful guidance for governments and decision-makers at global and national levels but there is also usually high diversity within countries and vulnerability assessments and adaptation planning also need to be conducted at finer, localized scales where the specific practices, stakeholders and communities, and local environmental conditions can be taken into account.

**Chapter 21** reports on global assessments of vulnerability of aquaculture to climate change, referring particularly to a study by Handisyde, Telfer and Ross (2017). The assessments considered sensitivity, exposure and adaptive capacity as the components of vulnerability.

**For freshwater aquaculture, that study found Asia to be the most vulnerable area, influenced strongly by the high production from the continent, with Viet Nam being the most vulnerable country in Asia, followed by Bangladesh, the Lao People's Democratic Republic and China. Belize, Honduras, Costa Rica and Ecuador were assessed as being the most vulnerable countries in the Americas, while Uganda, Nigeria and Egypt were found to be particularly vulnerable in Africa (Figure 8).**

In the case of brackish water production, Viet Nam, Egypt and Thailand emerged as having the highest vulnerabilities but the chapter draws attention to the countries with the lowest adaptive capacity to cope with the impacts of climate change, which included Senegal, Côte d'Ivoire, the United Republic of Tanzania, Madagascar, India, Bangladesh, Cambodia and Papua New Guinea.

**For marine aquaculture, Norway and Chile were identified as being the most vulnerable, reflecting the high production and the concentration of production on very few species in those countries in comparison to others. China, Viet Nam, and the Philippines were found to be the most vulnerable countries in Asia, while Madagascar was the most vulnerable country in Africa. Mozambique, Madagascar, Senegal and Papua New Guinea were identified as countries with particularly low adaptive capacity.**

**Chapter 21** presents a number of options for adaptation and building resilience in aquaculture and emphasizes that they should be applied in accordance with an ecosystem approach to aquaculture. They include:

- improved management of farms and choice of farmed species;

- improved spatial planning of farms that takes climate change-related risks into account;
- improved environmental monitoring involving users; and
- improved local, national and international coordination of prevention and mitigation.

According to the IPCC AR5 (Jimenez Cisneros *et al.*, 2014), climate change is projected to result in a significant reduction in renewable surface water and groundwater resources in most of the dry subtropical regions, which can be expected to lead to greater competition between different types of agriculture and between agriculture and other sectors. As with inland fisheries, this expected trend, and other inter-sectoral interactions, means that focusing only on adaptation within aquaculture is unlikely to be sufficient and effective reduction of vulnerability in the sector requires the integration of aquaculture into holistic, multi-sectoral watershed and coastal zone management and adaptive planning.

Aquaculture can also contribute to climate change adaptation in other sectors. For example, culture-based fisheries could be used to alleviate the effects of reduced recruitment in capture fisheries as a result of change. Aquaculture is also frequently seen as a promising alternative livelihood for fishers and other stakeholders when capture fisheries can no longer support them because of climate change, over-exploitation and other factors.

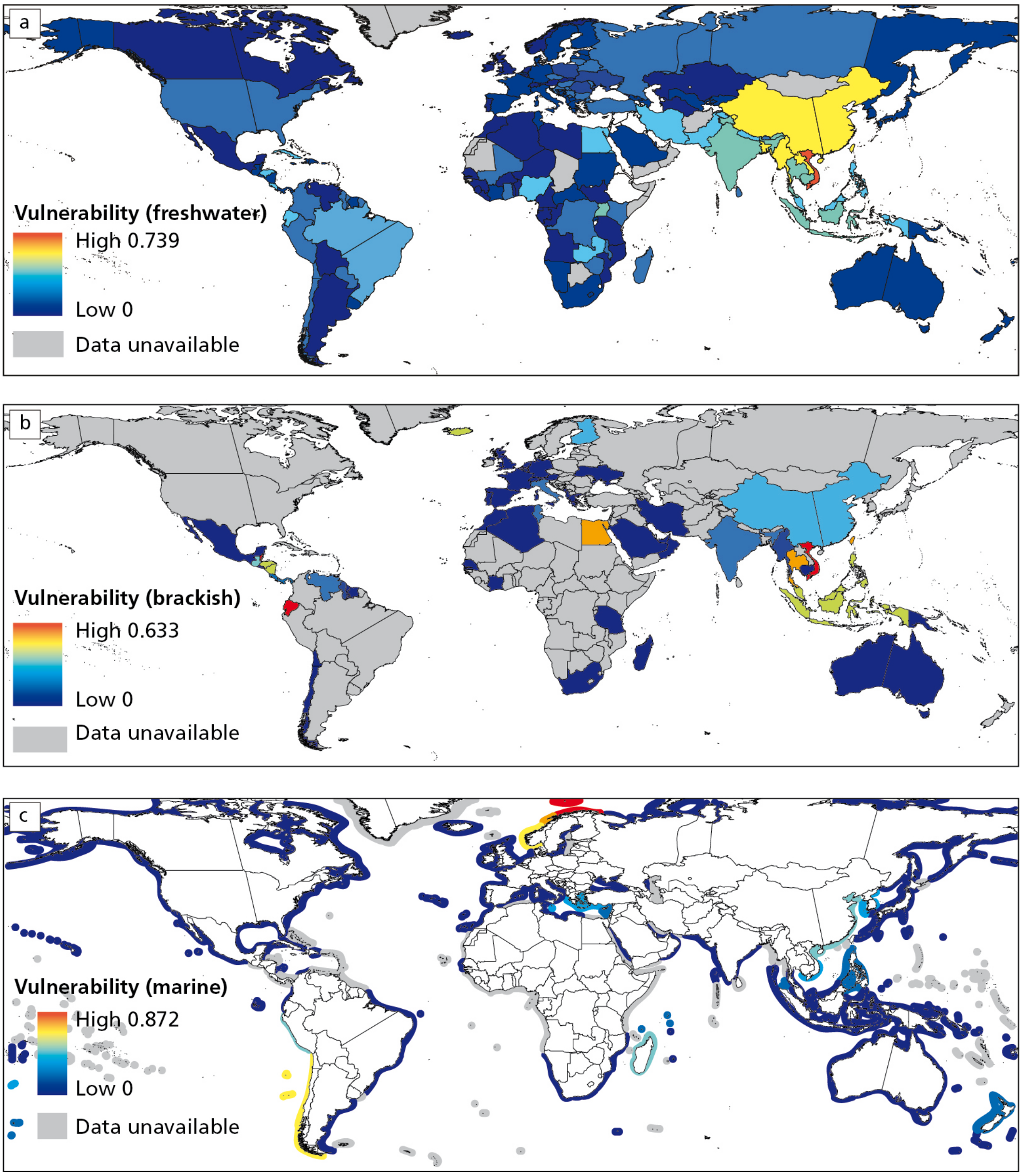
A common message across the three chapters on aquaculture is that there are important gaps in current knowledge and understanding of scientific, institutional and socio-economic aspects of the sector and the likely impacts of change. These gaps, examples of which are presented in the chapters, hinder the effectiveness of adaptation in the sector, particularly in developing countries. In general, ensuring that adaptations are consistent with the ecosystem approach to aquaculture (FAO, 2010) would provide a good foundation for success and effectiveness.

### Box 3. Aquaculture interactions with fisheries and agriculture

Interactions between aquaculture and fisheries and agriculture can either exacerbate the impacts and problems of climate change or help to create solutions for adaptation. Potential interactions and measures to address them include: increase in the number of escapees from aquaculture farms as a result of increased frequency and intensity of extreme weather events; consumption of water by aquaculture adding to competition for the resource in places where availability and quality of freshwater is reduced by climate change; aquaculture negatively affected if the impacts of climate change on the availability of fishmeal and fish oil are negative.

Measures that can minimize these impacts and foster adaptation include adequate regulations on movement of aquatic germplasm, certification or modification of farming equipment and practices, as well as technological and managerial improvements. Integrated, multi-sectoral policies, legal and regulatory frameworks and actions are also essential to address competing practices between sub-sectors (**Chapter 22**).

FIGURE 8. **Relative vulnerability† of aquaculture to climate change at global level††; a) in freshwater, b) in brackish water, c) in the marine environment (shown as a 50 km buffer zone from coasts).**




*Source:* Handisyde, Telfer and Ross 2017

# 10 Impacts of climate-driven extreme events and disasters

In 2017, a large number of unusual weather and climate events were recorded (**Chapter 23**). Hurricane Maria, a Category 5 hurricane which hit Dominica in September 2017, resulted in damages and losses amounting to 226 percent of Dominica's 2016 gross domestic product (Government of Dominica, 2018). An extreme weather and climate event is generally defined as "the occurrence of a value of a weather or climate variable above or below a threshold value near the upper or lower ends of the range of observed values of the variable"(Seneviratne *et al.*, 2012 in **Chapter 23**). Even if not extreme in a statistical sense, a weather or climate event, or two or more such events occurring simultaneously, can be considered to be extreme if they have high impacts or consequences for people, the environment or their infrastructure. While the attribution of extreme events is frequently difficult, there is growing confidence that the number of extreme events being observed in several regions is on the increase, and that this increase is related to anthropogenic climate change. Climate-related disasters now account for more than 80 percent of all disaster events, with large social and economic impacts, including displacement of people and populations (UNISDR, 2015). Fisheries and aquaculture face serious threats from extreme events such as cyclone, storm surge, flooding and extreme sea level rise, as can be seen from many examples in the preceding chapters. Extreme temperatures in the ocean are increasingly seen as another important influence on fisheries with profound ecological impacts well beyond coral bleaching. For example, the record landings of lobsters as a result of the 2012 heat wave in the Gulf of Maine outstripped market demand for the product, which contributed to a price collapse that threatened the livelihoods of the lobster fishers in both the United States of America and Canada. A recent FAO review of 74 post-disaster needs assessments conducted in 53 developing countries indicates that, while between 2006 and 2016 fisheries bore only three percent of the total impact of medium-to large-scale natural disasters, including climate extremes, on the agriculture sector, there are significant information gaps on the impacts on the sector and more specifically on aquaculture.

**A warmer climate can be expected to disrupt the hydrological cycle, resulting in changes in the frequency and intensity of extreme events, as well as to their timing, duration and geographic distribution. Not all extreme events necessarily result in a disaster and the extent of their impacts on fisheries and aquaculture will be dependent on how exposed and vulnerable the socio-ecological systems are, as well as their capacity to respond.**

It is to be expected, whatever actions are taken, that there will be extreme events in the future and an important message from **Chapter 23** is that existing approaches to damage and loss assessment from climate-related disasters in fisheries and aquaculture need to be improved, and should be linked to the evaluations under the Warsaw International Mechanism on Loss and Damage. With the increased and increasing number of extreme events and the likelihood of resulting disasters, there is an urgent need to invest in coherent and convergent disaster risk reduction and adaptation measures and preparedness for climate resilience to anticipate, prevent, prepare for, reduce the impact of and respond to extreme events and/or disasters affecting the fisheries and aquaculture sector. This should lead to a shift from reactive management after disasters have occurred, to proactive management and risk reduction of climate risks and hazards.

# 11 Hazards in food safety and aquatic animal health

Climate change is leading to changes in, amongst other features, the temperature, oxygen availability, pH and salinity of water and the incidence and intensity of extreme weather events, all of which can have impacts on food safety and biosecurity (**Chapter 24**). For example, the growth rates of pathogenic bacteria that occur in the marine environment have been found to increase at higher water temperatures, while changes in seasonality and other environmental conditions can influence the incidence of parasites and some food-borne viruses. Changes in the environment can also modify dynamics of aquatic species as intermediate and definitive hosts of foodborne parasites.

This changing environment will lead to the need for new food safety risk assessments to consider specific and emerging food safety hazards, which will inform risk management, including policy-making and decision-making. Coping with climate-driven changes will require giving greater attention to monitoring of key environmental parameters, including water and air temperature, pH and salinity, to enable advance prediction of imminent problems related to food safety such as the incidence of toxins, pathogens and contaminants in bivalve molluscs and fish species that are more susceptible to such threats.

**Implementation of effective early warning systems will need collaboration between the relevant sectors and stakeholders, including those responsible for aquatic animal health, the marine environment and food safety and public health, at both national and international levels.**

Aquaculture development is leading to more intense production so as to attain economic profitability, but this has the effect of increasing the probabilities of disease outbreaks as well as the challenges in controlling them (**Chapter 24**). Climate change frequently exacerbates these hazards. It can have impacts on the production environment, for example on the occurrence and virulence of pathogens, the susceptibility of the organisms being cultured to pathogens and infections, and the risk of escapes from production systems impacted by extreme events.The likelihood and consequences of climate change related events on aquaculture require urgent actions from different stakeholder groups ensuring: i) that minimal risk assessment and management are done to address climate change threats; ii) that management conditions are improved to reduce exposure to climate change, for example improved spatial planning of farms; and iii) ensuring implementation of an effective biosecurity plan that includes emergency preparedness and communication, and emphasizes prevention, biosecurity and health management practices

As with risk management in food safety, managing risks for animal health will require collaboration, sharing of responsibilities and active, long-term engagement of all the relevant authorities and other stakeholders. Risk management through prevention, mitigation and coping include generic biosecurity measures such as best practices (including improved spatial planning, as discussed in **Chapter 21**), border controls and emergency preparedness and risk communication.

**Addressing biosecurity and aquatic animal health challenges requires effective implementation of biosecurity plans that includes emergency preparedness and communication, and emphasizes prevention, biosecurity and health management practices.**

### Box 4. Key elements regarding climate change food safety and biosecurity

Impacts of climate change on food safety and diseases will lead to the need for new risk assessment exercises for food safety and biosecurity to ensure that emerging hazards are addressed. Coping with climate-driven changes will require giving greater attention to monitoring of key environmental parameters, including water and air temperature, oxygen, pH and salinity, to enable advance prediction of imminent problems related to food safety such as the incidence of toxins, pathogens and contaminants in bivalve molluscs and fish but also diseases that can affect them. Implementation of effective early warning systems will need collaboration between the relevant sectors and stakeholders, including those responsible for aquatic animal health, the marine environment and food safety and public health, at both national and international levels.

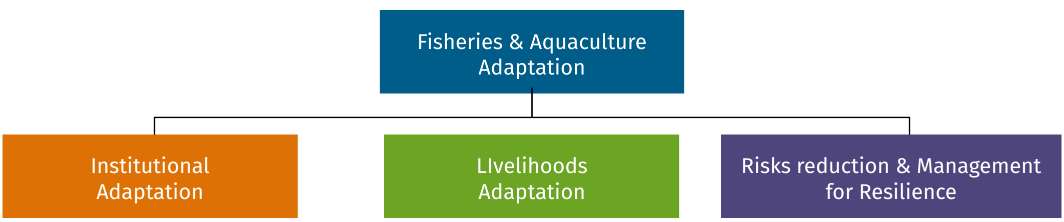
# 12 Adaptation in fisheries and aquaculture

Climate change is challenging the effectiveness of contemporary fishery and aquaculture management and gives rise to significant additional uncertainties and risks to fishers and fish farmers' livelihoods and to the fishing and aquaculture industry. Although there is a wide range of tools and approaches that are being or can be used to respond to change in the fisheries and aquaculture sector, many of them will have to be modified to increase flexibility and reduce surprise/unanticipated outcomes. In addition, although different types of adaptation tools have been developed over the past two decades, there is minimal guidance specifically aimed at developing adaptation strategies for the sector. **Chapter 25** "Methods and tools for climate change adaptation in fisheries and aquaculture" aims to contribute to filling this gap by providing a portfolio of available tools and approaches recommended and currently available in capture marine and inland fisheries and in aquaculture, as well as guidance for selecting, implementing and monitoring the effectiveness of adaptation actions while limiting maladaptation.

**The Technical Paper provides examples of adaptation tools within three primary entry categories: institutional and management, those addressing livelihoods and, thirdly, measures intended to manage and mitigate risks and thereby strengthen resilience (Figure 9).**

A critical part of the adaptation-making process is assessing the current climate variability and considering future change as a prerequisite for determining low or no regret adaptation and longer-term adaptation respectively. The vulnerability assessment of fishery and aquaculture systems should start with determining clear objectives in consultation with key stakeholders and should be grounded in the best available science as well as build on traditional ecological knowledge and other stakeholders' knowledge. Although the focus

FIGURE 9. **Categories of adaptation tools and approaches as described in Chapter 25**

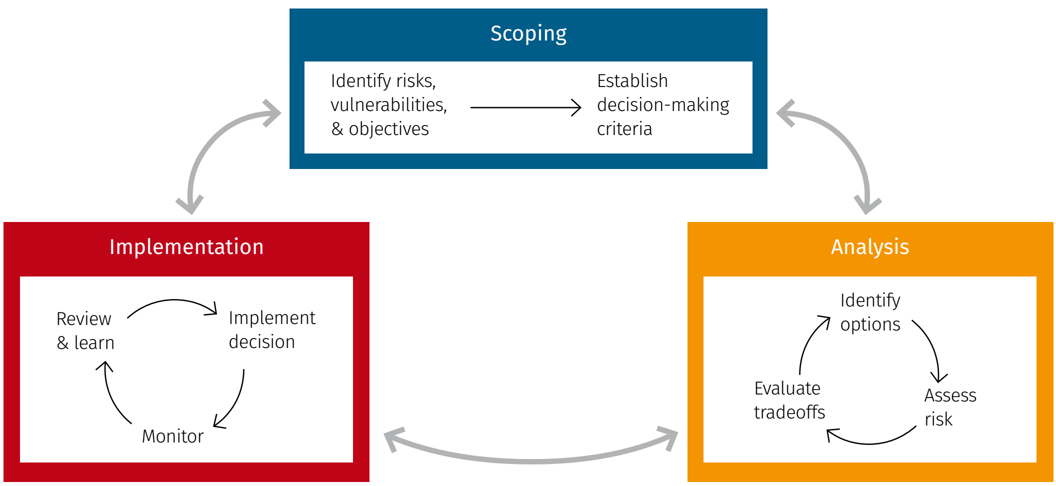


is on climate change, other elements should be considered that could have an impact on the system's vulnerability such as poverty, gender, socio-economic and institutional contexts, etc. The analysis of the results of the vulnerability assessment can then be used to develop a climate adaptation strategy or plan for a given context.

**Adaptation should be seen and implemented as an ongoing and iterative process, equivalent in many respects to adaptive management in fisheries (Figure 10).**

The impacts of climate change do not respect human-made boundaries, and implications for transboundary issues, such as changing stock distributions (see, for example, **Chapter 5**) need to be anticipated, as far as possible, and suitable measures put in place to address them with a minimum of conflict. Another consideration that should be taken into account when developing an adaptation plan is to avoid the cost of inaction (i.e. avoid cases where future costs are bigger than current costs) as well as lose–lose (i.e. investments with no short-term benefits and long-term losses) or win–lose adaptation (i.e. investments with some short-term benefits but long-term losses). **Chapter 25** provides some guiding principles to limit these within the sectors but also between sectors (e.g. agriculture and inland fisheries).

FIGURE 10. **An iterative risk management framework incorporating system feedbacks**




*Source:* Jones *et al.*, 2014

13

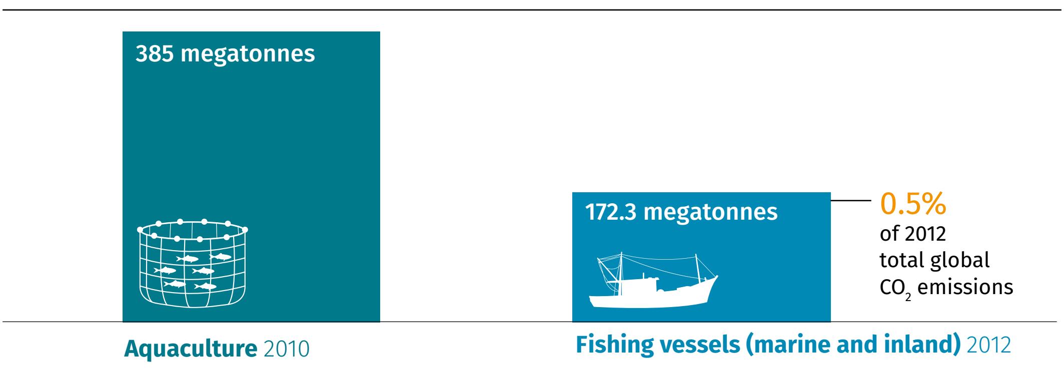
# Measures and tools to reduce energy use and GHG emission in fisheries and aquaculture

**Chapter 27** reports that the estimated global emission of carbon dioxide by fishing vessels, both marine and inland, in 2012 was 172.3 megatonnes, which was about 0.5 percent of total global emissions that year. The aquaculture industry, including the emissions involved in capturing fish for feed, was estimated to have led to the emission of 385 megatonnes of carbon dioxide in 2010. Overall, the energy use of protein production per unit mass of fish is comparable to chicken, but is much less than that from other land-based systems such as pork and beef. Fisheries and aquaculture are therefore only minor contributors to emissions but, nevertheless, there are options for reducing fuel use and GHG emissions, which should be seen as important objectives in operations and management in the sector.

**In the case of capture fisheries, reductions of between 10 percent and 30 percent could be attained through the use of efficient engines and larger propellers in fishing vessels, as well as through improving vessel shapes and other hull modifications and simply by reducing the mean speed of vessels.**

Further opportunities include using fishing gears that require less fuel – for example switching from pelagic trawl to purse seine or from otter trawl to pair trawl – which would reduce GHG emissions, although they could have impacts on catchability and fishing efficiency, which would need to be considered. In the case of towed fishing gears, the use of multi-rig gear, efficient otter boards, fishing off the bottom, use of lighter, high-strength materials and larger mesh sizes can all increase fuel efficiency and reduce carbon

**Estimated global emission of $CO_2$**



intensity (the amount of carbon dioxide emitted per unit weight of fish landed), as can using light emitting diode (LED) lights in those fisheries that attract fish with lights. Opportunities also exist in the facilities on land, with an obvious gain from using energy from renewable energy systems such as wind and solar-powered generation of electricity.

The choice and application of management measures in capture fisheries can play a role in fuel consumption and GHG emissions and, as a general rule, measures that lead to reductions in fishing effort and enhance fish stocks, thereby enabling higher catches per unit effort, will result in reduced fuel use and emissions. As an example of potential impacts, area closures are a widely applied measure that can contribute to ensuring high and sustainable stock biomass, and therefore fuel efficiency, but can also result in vessels having to fish in more distant or sub-optimal areas, thereby decreasing efficiency. Chapter 27 provides other examples that demonstrate the importance of including impacts on fuel efficiency as an objective in fisheries management planning.

**There are also opportunities to reduce GHG emissions in aquaculture, which include improved technologies to increase efficiency in the use of inputs, greater reliance on energy from renewable sources, improving feed conversion rates, and switching from feed based on fish to feed made from crop-based ingredients that have lower carbon footprint. The integration of pond aquaculture with agriculture is also a potential option for reducing fuel consumption and emissions.**

# 14 Concluding comments

The structure and contents of the Technical Paper illustrate the multi-faceted and inter-connected complexity of the fisheries and aquaculture sector and the interactions between the sector and the wider environment and human environments. The impacts of climate change ramify through these systems and the impacts of physical changes, for example in temperature or pH, can have impacts, direct or indirect, on any or all of the different facets, from target or cultured species through to human health and well-being.

**One of the most important messages coming from the Technical Paper as a whole is that efforts to adapt to and mitigate climate change should be planned and implemented with full consideration of this complexity and how any new interventions will affect not only the immediate targets of the actions but the system as a whole. Failure to do this will increase the risks of inefficiency, failure of the actions, and of maladaptation.**

The consequences of inefficient, poorly planned adaptation are likely to exacerbate the impacts of climate change, while appropriate adaptations will do much to counteract such impacts.

A second important message is the reminder, recurring through many of the chapters, of the critical importance of fisheries and aquaculture for millions of people struggling to maintain reasonable livelihoods through the sector. These are the people who are most vulnerable to the impacts of climate change, which adds to the many threats and obstacles that already confront them in their day-to-day lives.

**Effective adaptation will be required across all scales and sectors of fisheries and aquaculture in order to strengthen and maintain productive and resilient aquatic ecosystems and the benefits derived from them, but particular attention needs to be given to the most vulnerable if the sector is to continue to contribute to meeting global goals of poverty reduction and food security.**

In addition, because their poverty and marginalization are primary causes of their vulnerability, the eradication of poverty and provision of food security for the world's poor are fundamental to building their resilience to climate change.

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