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Impacts of climate change on fisheries and aquaculture

Synthesis of current knowledge, adaptation and mitigation options

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Synthesis of current knowledge, adaptation and mitigation options

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Preparation of this document

Preparation of this document started with the appointment of a task team within the FAO Fisheries and Aquaculture Department, led by Manuel Barange (Director) and including Tarûb Bahri (Marine fisheries), Malcolm Beveridge (Aquaculture), Simon Funge-Smith (Inland fisheries), Ari Gudmundsson (Mitigation), Daniela Kalikoski (Poverty nexus), Florence Poulain (Adaptation), Stefania Vannuccini (Supply and demand evolution) and Sylvie Wabbes (Extreme events). The task team designed the draft contents of the Technical Paper, and took responsibility for structuring the different sections. At a later stage the task team took responsibility for commissioning and receiving reviews of the different chapters.

The first workshop of technical experts took place in Rome, at the FAO headquarters on 28 to 29 July 2017, bringing together approximately 30 participants, many of whom were identified as leading contributors. The objectives of this workshop were to design the contents and objectives of a Technical Paper that would provide synthetic information aimed primarily at policymakers, fisheries managers and practitioners, with a view to assisting countries in the development of their Nationally Determined Contributions (NDCs) and complementary needs.

The different chapters were commissioned to international experts, who submitted their first drafts prior to the second workshop of technical experts, held also at FAO in Rome on 15 to 17 January 2018. All chapter leads attended the workshop. At the meeting the chapters were discussed and debated, and the adaptation strategies agreed upon. Extensive conversations were held to ensure consistency of format and messaging, and to identify gaps in knowledge and/or geographical coverage. The experts were then requested to revise and re-submit their drafts for final consideration, and additional chapters were also commissioned.

All the chapters were peer-reviewed before being accepted (see Acknowledgements), and a technical editor (Professor Kevern Cochrane, Rhodes University, South Africa) was appointed to ensure consistency in the use of language and concepts. To ensure uncertainty statements were not only consistent but well-aligned to parallel endeavours, authors and editors were asked to be guided in their statements by the IPCC guidance note on the consistent treatment of uncertainties (Mastrandrea *et al*., 2010). Language editing, formatting and layout were provided by Dawn Ashby (Plymouth Marine Laboratory, UK) and Claire Attwood and Wendy Worrall (Fishmedia, South Africa).

Abstract

The 2015 Paris Climate Agreement 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 systems. The inclusion of adaptation measures in the fisheries and aquaculture sector is currently hampered by a widespread lack of targeted analyses of the sector's vulnerabilities to climate change and associated risks, as well as the opportunities and responses available. This report provides the most up-to-date information on the disaggregated impacts of climate change for marine and inland fisheries, and aquaculture, in the context of poverty alleviation and the differential dependency of countries on fish and fishery resources. The work is 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.

In marine regions model projections suggest decreases in maximum catch potential in the world's exclusive economic zones of between 2.8 percent and 5.3 percent by 2050 according to greenhouse gas emission scenario RCP2.6, and between 7.0 percent and 12.1 percent according to greenhouse gas emission scenario RCP8.5, also by 2050. While at the global scale this average is not particularly large, the impacts are much greater at regional scale, because projected changes in catch potential vary substantially between regions. Although estimates are subject to significant variability, the biggest decreases can be expected in the tropics, mostly in the South Pacific regions. For the high latitude regions, catch potential is projected to increase, or show less of a decrease than in the tropics. It is important to note that these projections only reflect changes in the capacity of the oceans to produce fish, and do not consider the management decisions that may or may not be taken in response. It is concluded that the interaction between ecosystem changes and management responses is crucial to minimize the threats and maximize the opportunities emerging from climate change. Production changes are partly a result of expected shifts in the distribution of species, which are likely to cause conflicts between users, both within and between countries.

The vulnerability of marine fisheries to climate change and existing and potential responses to adapt to the changes are examined in more detail for 13 different marine regions covering a range of ecological, social and economic conditions. It is concluded that adaptations to climate change must be undertaken within the multifaceted context of fisheries, with any additional measures or actions to address climate change complementing overall governance for sustainable use. It is recognized that some of these measures will require institutional adaptation.

In relation to inland fisheries the Technical Paper highlights that in the competition for scarce water resources the valuable contributions of inland fisheries are frequently not recognized or undervalued. The Paper assesses country by country impacts and provides indications of whether levels of stress are expected to change and to what extent. Pakistan, Iraq, Morocco and Spain are highlighted as countries that are currently facing high stresses that are projected to become even higher in the future. Myanmar, Cambodia, the Congo, the Central African Republic and Colombia, are among the countries that were found to be under low stress at present and are projected to remain under low stress in the future. The implications of climate change for individuals, communities and countries will depend on their exposure, sensitivity and adaptive

capacity, but in general they can be expected to be significant. Some positive impacts are also identified, like increased precipitation leading to the expansion and improved connectivity between some fish habitats, but to take advantage of them, new investments as well as flexibility in policies, laws and regulations, and post-harvest processes are needed. It is recommended that adaptive management measures be within the framework of an ecosystem approach to fisheries to maximize success.

Short-term climate change impacts on aquaculture can include losses of production and infrastructure arising from extreme events such as floods, increased risks of diseases, parasites and harmful algal blooms. Long-term impacts can include reduced availability of wild seed as well as reduced precipitation leading to increasing competition for freshwater. Viet Nam, Bangladesh, the Lao People's Democratic Republic and China were estimated to be the most vulnerable countries in Asia, with Belize, Honduras, Costa Rica and Ecuador the most vulnerable in the Americas, for freshwater aquaculture. Uganda, Nigeria and Egypt were found to be particularly vulnerable in Africa. In the case of brackish water production, Viet Nam, Egypt and Thailand emerged as having the highest vulnerabilities. For marine aquaculture, Norway and Chile were identified as being the most vulnerable, due to their high production, although China, Viet Nam, the Philippines and Madagascar were also considered to be highly vulnerable. Climate-driven changes in temperature, precipitation, ocean acidification, incidence and extent of hypoxia and sea level rise, amongst others, are expected to have long-term impacts in the aquaculture sector at multiple scales. Options for adaptation and resilience building are offered, noting that interactions between aquaculture, fisheries and agriculture can either exacerbate the impacts or help create solutions for adaptation.

The Technical Paper also investigates the impacts of extreme events, as there is growing confidence that their number is on the increase in several regions, and 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. Not all extreme events necessarily result in a disaster, and the extent of their impacts on fisheries and aquaculture will depend on how exposed and vulnerable the socio-ecological systems are as well as their capacity to respond.

An often unrecognized impact of climate change is on food safety, for example through changes in the growth rates of pathogenic marine bacteria, or on the incidence of parasites and food-borne viruses. Climate change may also bring increased risks for animal health, particularly in the rapidly growing aquaculture sector, for example by changing the occurrence and virulence of pathogens or the susceptibility of the organisms being cultured to pathogens and infections. Effective biosecurity plans that emphasize prevention are essential.

In the final sections the Technical Paper recognizes that the impacts of climate change on the fisheries and aquaculture sector will be determined by the sector's ability to adapt. Guidance on the tools and methods available to facilitate and strengthen such adaptation is provided. Because each specific fishery or fishery/aquaculture enterprise exists within unique contexts, climate change adaptations must start with a good understanding of a given fishery or aquaculture system and a reliable assessment of potential future climate change. The Paper provides information on the tools available to inform decision-makers of particular adaptation investments and of the process to develop and implement adaptation strategies. It presents examples of tools within three primary adaptation entries: institutional and management, those addressing livelihoods and, thirdly, measures intended to manage and mitigate risks and thereby strengthen resilience. It is noted that adaptation should be implemented as an ongoing and iterative process, equivalent in many respects to adaptive management in fisheries.

Finally, the contributions of the sector to global emissions of carbon dioxide are presented. Globally, fishing vessels (including inland vessels) emitted 172.3 million tonnes of CO_2 in 2012, about 0.5 percent of total global CO_2 emissions that year. For the aquaculture industry, it was estimated that 385 million tonnes of CO_2 equivalent (CO_2 e) was emitted in 2010, around 7 percent of those from agriculture. While the sector is a small contributor, options for reducing fuel use and greenhouse gas emissions are identified. In the case of capture fisheries, reductions of between 10 percent and 30 percent could be attained through use of efficient engines, larger propellers, as well as through improving vessel shapes or simply by reducing the mean speed of vessels. There are also opportunities to reduce greenhouse gas emissions in aquaculture, which include improved technologies to increase efficiency, use of renewable energy sources, and improving feed conversion rates, among others.

The Technical Paper highlights the multifaceted and interconnected complexity of fisheries and aquaculture, through which direct and indirect impacts of climate change will materialize. Efforts to adapt to and mitigate climate change should be planned and implemented with full consideration of this complexity. Failure to do so would increase inefficiency and maladaptation, exacerbating rather than reducing impacts.

Finally, the Technical Paper is a reminder 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, and particular attention needs to be given to them while designing adaptation measures if the sector is to continue to contribute to meeting global goals of poverty reduction and food security.

Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 2018.
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Contents

Foreword

By 2050 humans will face the challenge of having to provide food and livelihoods to a population likely to exceed nine billion people. This challenge is well reflected in the United Nations Agenda 2030 for Sustainable Development, a global commitment to end poverty and hunger and to ensure that economic, social and technological progress occurs in harmony with nature, through the sustainable management of natural resources.

An additional consideration to the above challenge is that it will have to be met at a time when the effects of climate change will be increasingly prominent. The two cannot be separated and, indeed, the 2015 Paris Climate Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) explicitly recognizes the fundamental priority of safeguarding food security and ending hunger when taking climate action.

One of the novelties of the Paris Climate Agreement is the inclusion of a long-term adaptation goal – *to increase the ability to adapt to the adverse impacts of climate change and foster climate resilience …/… in a manner that does not threaten food production* – alongside the goal for mitigation. It also notes that the level of adaptation needed will be determined by the success of mitigation activities. To implement the Agreement member states are required to prepare, communicate and maintain successive Nationally Determined Contributions (NDCs), submitted every five years to the UNFCCC secretariat. The next round of NDCs (new or updated) is to be submitted by 2020.

This FAO Technical Paper emerges from the above challenges, first in recognition of the significant role that fisheries (both marine and inland) and aquaculture play in addressing them. The fisheries and aquaculture sector supports the livelihoods of between 10 percent and 12 percent of the world's population, and in the last five decades its production has significantly outpaced population growth (FAO, 2016), thus increasing its contribution to food security and nutrition (HLPE, 2014). Second, while the fisheries and aquaculture sectors are included in the NDCs of approximately 60 countries, the level of ambition is typically low, partially because of the difficulty of making explicit sectoral commitments when climate change projections remain highly uncertain.

In 2009, and in response to a request from the twenty-seventh session of the Committee on Fisheries (COFI), the FAO Fisheries and Aquaculture Department undertook a scoping study to identify the key issues in relation to climate change and fisheries through three comprehensive technical papers (Cochrane *et al*., eds., 2009). Nine years later the political framework has dramatically evolved, the evidence has increased exponentially, as has the importance of marine and ocean matters in climate change circles. For example, in 2016 the Intergovernmental Panel on Climate Change (IPCC) commissioned a Special Report on Oceans and the Cryosphere in a Changing Climate (SROCC), to report in 2019.

This Technical Paper is intended to update the Cochrane *et al*., eds. (2009) Technical Paper, and be of fundamental use to countries in their NDC development and implementation, including resource mobilization efforts. In this context it is significant to note that Article 9 of the Paris Climate Agreement stipulates that financial resources will be provided to assist developing country Parties with respect to their mitigation and adaptation obligations.

It is often mentioned that the fisheries and aquaculture sector is extremely dynamic and used to dealing with change, as historical patterns of changes in marine resources demonstrate (Baumgartner, Soutar and Ferreira-Bartrina, 1992), but the magnitude and uni-directionality of future climate-driven changes demand greater preparedness in responding to the changes. For example the Fifth Assessment Report of the IPCC concludes, with high confidence, that global marine species redistribution and marine biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity by the mid-twenty-first century (IPCC, 2014). Biodiversity reductions in sensitive areas, such as northern latitudinal basins, are also expected in freshwater ecosystems (Comte and Olden, 2017). Preparedness is indeed essential to translate changes into opportunities, while the opposite leads to maladaptation and unfulfilled prospects. Furthermore, the IPCC notes that adaptation is place- and context-specific, with no single approach for reducing risks being appropriate across all settings (IPCC, 2014). Understanding the direction, speed, intensity and place of change is thus a prerequisite to effective adaptation.

A fundamental principle in the preparation of this Technical Paper was that the report would not provide a comprehensive review of all the available evidence of, and possible responses to climate change, but that it would be a synthetic volume aimed primarily at policymakers, fisheries managers and practitioners, with a view to assisting countries in the development of their NDCs. The work (see Preparation of this document) was tailored around two technical workshops in Rome (July 2017 and January 2018), and engaged over 100 contributors.

The Technical Paper recognizes the importance of contextualizing the topic of climate change in fisheries and aquaculture in terms of poverty alleviation and the existing policy commitments such as UN Agenda 2030 and the Paris Climate Agreement (Chapter 2), and the current and expected socio-economic dependencies of the sector (Chapter 3). It was designed to include marine (Chapters 4 to 17) and inland (Chapters 18, 19, 26) capture fisheries, as well as aquaculture (Chapters 20 to 22), recognizing that the level of evidence and responses at global, regional and national scales differs between subsectors. While model projections for marine catch potential were computed for all countries, with the time and resources available it was not possible to provide dedicated chapters for all regions. However, every effort was made to ensure reasonably comprehensive geographical coverage that would provide good representation of the types of changes, impacts and responses that are taking place in the sector as a whole. Figure 1 illustrates the geographical areas covered by the marine fisheries projections and the regional chapters. While inland fisheries are addressed for all the major fish producers, Figure 1 also illustrates the location of the eight major river basins discussed in detail in Chapter 19. Aquaculture impacts are discussed according to their vulnerability and adaptation options, supported by case studies, in Chapter 21.

It was also agreed to consider disasters and extreme events (Chapter 23) and health and food safety hazards (Chapter 24) in addition to the impacts of long-term patterns of change. All these pieces of evidence were translated into effective and explicit adaptation (Chapter 25) and mitigation (Chapter 27) strategies and tools, also taking into consideration the potential adaptations to climate change from other sectors (Chapter 26).

It is hoped that the Technical Paper will be used extensively in the development of programmes of work, particularly in relation to adaptation measures to climate change in the sector, by UN agencies, national institutions and NGOs.

The different chapters were commissioned to international experts, who submitted their drafts prior to the second expert workshop, held in Rome on 15 to 17 January 2018. At the workshop the chapters were discussed and debated, and the options and measures available for adaptation agreed upon. The experts were then requested to revise and re-submit their drafts for final consideration. All the chapters were peer-reviewed before being accepted, and a technical editor was appointed to ensure consistency in the use of language and concepts. To ensure any uncertainty statements presented in the chapters were not only consistent but well-aligned to parallel endeavours, authors and editors were guided by the IPCC guidance note on the consistent treatment of uncertainties (Mastrandrea *et al*., 2010).

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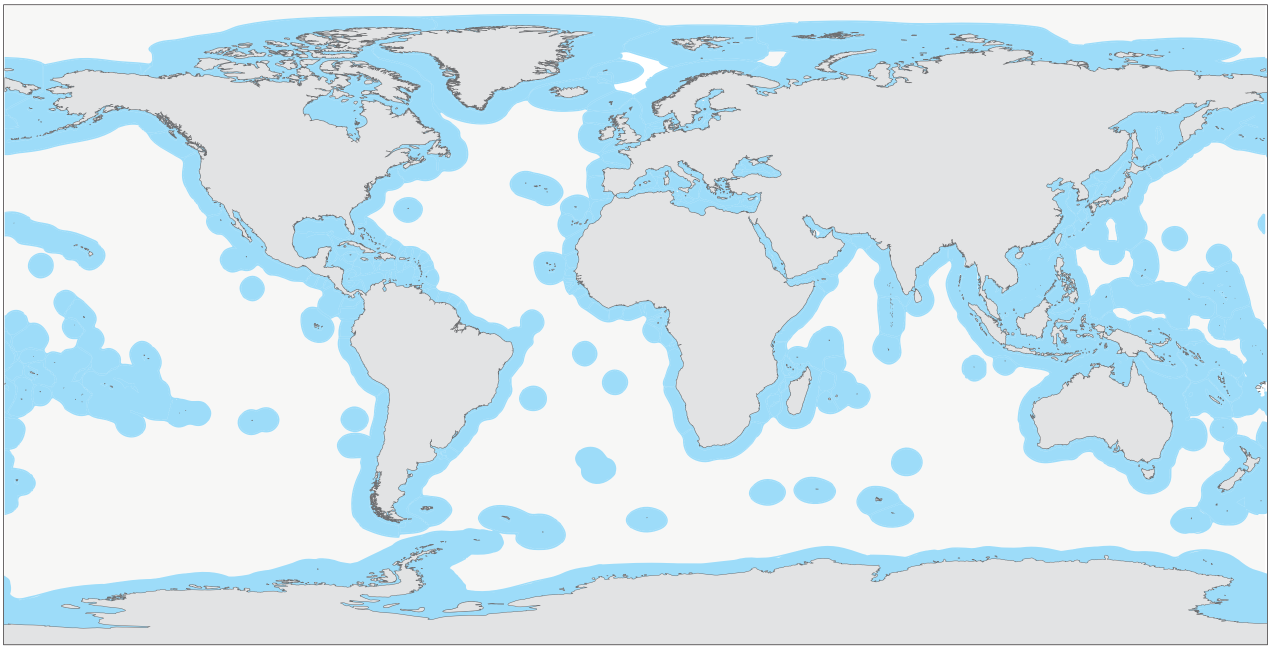
FIGURE 1

Conceptual map of the geographic areas covered by the Technical Paper. Figure 1a. Country projections of marine fisheries catch presented in Chapter 4. Pressures on inland fisheries in 26 subregions and 149 individual countries are presented in Chapter 19. Country by country analysis of aquaculture is presented in Chapter 21. Figure 1b. Areas covered by the marine regional fisheries Chapters 5 to 17; the map also shows the location of the eight major river basins, the fisheries of which were assessed in the case studies presented in Chapter 19

a



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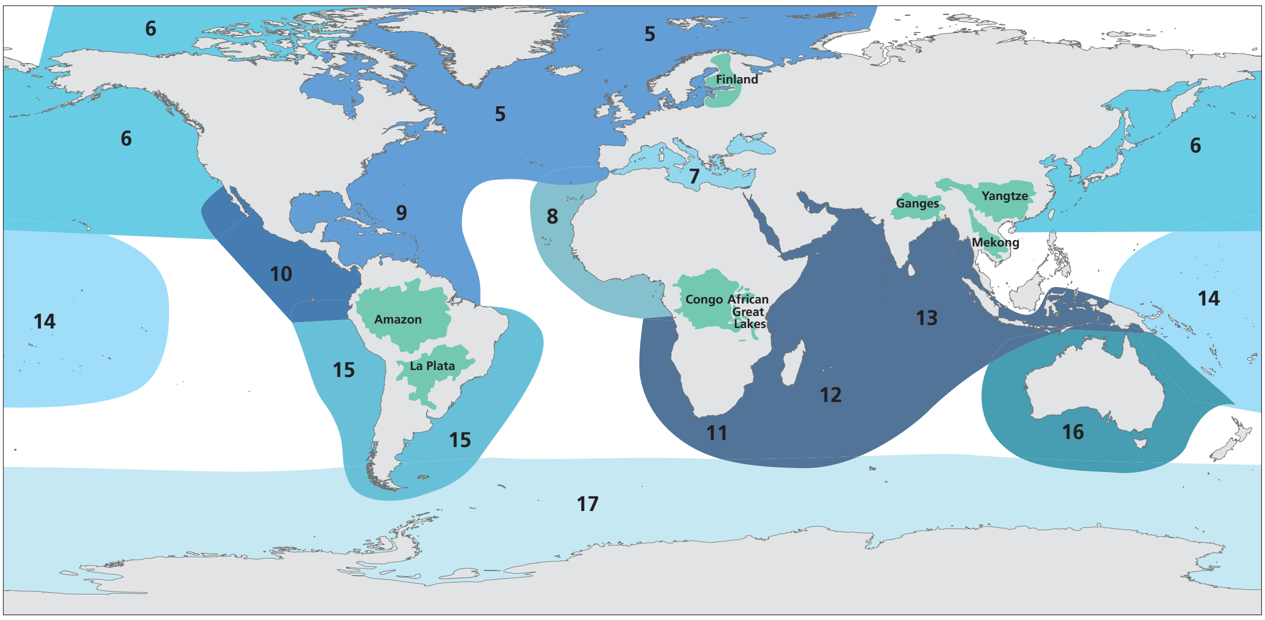

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Abbreviations and acronyms

AC	alternating current
ACCE	Antarctic Climate Change and the Environment (report)
AEUS	Atlantic Equatorial Upwelling System
AL	Agulhas leakage
AMO	Atlantic Multi-decadal Oscillation
AMOC	Atlantic Meridional Overturning Circulation
AM	adaptation measure
APECOSM-E	Apex Predators ECOSystem Model
APF	Antarctic Polar Front
AR4	Fourth Assessment Report (of the IPCC)
AR5	Fifth Assessment Report (of the IPCC)
BAU	business-as-usual
BBB	building back better
BCC	Benguela Current Commission
BCLME	Benguela Current Large Marine Ecosystem
BMP	Better management practice
CAMLR Convention	Convention on the Conservation of Antarctic Marine Living Resources
CBF	culture-based fisheries
CC4FISH	Climate Change Adaptation in the Eastern Caribbean Fisheries Sector Project
CCA	climate change adaptation
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CCI	Caribbean Challenge Initiative
CCLME	Canary Current Large Marine Ecosystem
CCS	Canary Current System
CCS	California Current System
CD	capacity development
CEAFM	community-based ecosystem approach to fisheries management
CECAF	FAO Fishery Committee for the Eastern Central Atlantic
CIL	cold intermediate layer
CLME+	Caribbean and North Brazil Shelf Large Marine Ecosystem
CMIP5	Climate Model Intercomparison Project version 5
CO_2	carbon dioxide
CO_2 e	CO_2 equivalent
COI	*Commission de l'Océan Indien* / Indian Ocean Commission
CPUE	catch per unit effort
CSR	corporate social responsibility
CVCA	climate vulnerability and capacity analysis

CVIs	community social vulnerability indices
DBEM	Dynamic Bioclimate Envelope Model
DC	direct current
DEC	daily energy consumption
DFO	Department of Fisheries and Oceans (Canada)
DHC	direct human consumption
DO	dissolved oxygen
DRM	disaster risk management
DWFNs	distant water fishing nations
EAA	ecosystem approach to aquaculture
EAC	East Australia Current
EAF	ecosystem approach to fisheries
EAP	East Asia/Pacific
EBS	Eastern Bering Sea
EBUS	eastern boundary upwelling systems
ECR	Economics of Climate Resilience (report)
EEZ	exclusive economic zone
EMPRES Food Safety	(FAO) Emergency Prevention System for Food Safety
ENSMN	ensemble mean
ENSO	El Niño-Southern Oscillation
ESM	Earth system models
EU	European Union
EUS	epizootic ulcerative syndrome
EWS	early warning system
FAD	fish aggregating device
FAO	Food and Agriculture Organization of the United Nations
FCR	feed conversion rates
FEWER	Fisheries Early Warning and Emergency Response (modules)
FFA	(Pacific Islands) Forum Fisheries Agency
FM	fishmeal
FMFO	fishmeal and fish oil
FO	fish oil
FUI	fuel use intensity
GAPS	Global Agriculture Perspectives System
GCLME	Guinea Current Large Marine Ecosystem
GCM	general circulation model (also referred to as "global climate model")
GCS	Guinea Current System
GFCM	General Fisheries Commission for the Mediterranean
GFDL–ESM	Geophysical Fluid Dynamic Laboratory Earth System Model
GHG	greenhouse gas
GIS	geographic information systems
GOA	Gulf of Alaska
GOM	Gulf of Mexico

GRPS	Global Risks Perception Survey
H_2S	hydrogen sulphide
HAB	harmful algal bloom
HACCP	Hazard Analysis and Critical Control Points
HCS	Humboldt Current System
HDI	Human Development Index
IATTC	Inter-American Tropical Tuna Commission
IC	internal combustion
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICE	internal combustion engine
ICES	International Council for the Exploration of the Sea
ICZM	integrated coastal zone management
IHHNV	Infectious hypodermic and haematopoietic necrosis virus
IIOE–2	International Indian Ocean Expedition – 2 programme
IMF	International Monetary Fund
INFOSAN	International Food Safety Authorities Network
IOD	Indian Ocean Dipole
IODE	Oceanographic Data and Information Exchange
IOTC	Indian Ocean Tuna Commission
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institute Pierre-Simon Laplace Climate Model
IPSL–CM5	Institute Pierre-Simon Laplace Climate Earth System Model
IRM	iterative risk management
IUU	illegal, unreported and unregulated (fishing)
LC	Leuwin Current
LDC	least developed countries
LED	light emitting diode
LIFDC	low-income food-deficit country
LME	large marine ecosystem
LMR	living marine resources
L-W	lose-win
MeHg	methylmercury
MH	metal halide
MOC	meridional overturning circulation
MPA	marine protected area
MPI–ESM	Max Planck Institute Earth System Model
MRC	Mekong River Commission
MSY	maximum sustainable yield
NACW	North Atlantic Central Water
NAFO	Northwest Atlantic Fisheries Organization
NAOMZ	North Atlantic oxygen minimum zone
NAPA	National Adaptation Programme of Action
NAP	National Adaptation Plan/National Action Plan
NASCO	North Atlantic Salmon Conservation Organization

NBC	North Brazil Current
NDCs	Nationally Determined Contributions
NEAFC	North East Atlantic Fisheries Commission
NEPAD	New Partnership for Africa's Development
NETP	Northeast Tropical Pacific
NGO	non-governmental organization
NMFS	National Marine Fisheries Service (United States of America)
NOAA	National Oceanic and Atmospheric Administration (United States of America)
NPP	net primary productivity
NPTZ	North Pacific Transition Zone
OA	ocean acidification
OIE	*Office International des Epizooties*
OMZ	oxygen minimum zone
OSPESCA	Central America Fisheries and Aquaculture Organization
PA	Paris Agreement
PaV1	*Panulirus argus* Virus 1
PCAC	Pacific Central American Coastal
PDNA	post-disaster needs assessment
PDF	probability density function
PDO	Pacific Decadal Oscillation
PES	payment for ecosystem services
PFTs	plankton functional types
PI	potential impacts
PICES	North Pacific Marine Science Organization
PICTs	Pacific island countries and territories
pIOD	positive Indian Ocean Dipole
PIOMAS	Pan-Arctic Ice Modeling and Assimilation System
PLD	pelagic larval duration
PNA	Parties to the Nauru Agreement
PPCR	Programme for Climate Resilience project
PRA	participatory rural appraisal
PV	photovoltaic
RAS	recirculating aquaculture system
RASFF	Rapid Alert System for Food and Feed
RBM	robust decision-making
RCP	representative concentration pathway
REDD+	reducing emissions from deforestation and forest degradation
RFB	regional fishery body
RFMO	regional fisheries management organization
ROA	real option analysis
RRA	rapid rural appraisal
SA	South and Southeast Asian
SADC	Southern African Development Community

SAFMC	South Atlantic Fishery Management Council
SAM	Southern Annular Mode
SBSTA	Subsidiary Body for Scientific and Technological Advice
SCAR	Scientific Committee for Antarctic Research
SCTR	Seychelles-Chagos Thermocline Ridge
SDG	Sustainable Development Goal
SE USA	southeast shelf of the United States of America
SI–CCME	Strategic Initiative for the Study of Climate Impacts on Marine Ecosystems
SIDS	small island developing states
SIOFA	South Indian Ocean Fisheries Agreement
SLR	sea level rise
SPAGS	spawning aggregation site
SPC	Oceanic Fisheries Programme of the Pacific Community
SPF	small pelagic fish
SPS Agreement	Agreement on the Application of Sanitary and Phytosanitary Measures Agreement
SREX	IPCC Special report on managing the risks of extreme events and disasters to advance climate change adaptation
SS	storm surge
SSF	small-scale fisheries
SSF Guidelines	(FAO) Voluntary guidelines for securing sustainable small-scale fisheries in the context of food security and poverty eradication
SSP	shared socio-economic pathway
SSS	sea surface salinity
SST	sea surface temperature
SWIOFC	Southwest Indian Ocean Fisheries Commission
TAC	total allowable catch
TAR	Third Assessment Report (of the IPCC)
TCU	total cumulative upwelling
TEK	traditional ecological knowledge
TPP	temperature preference profile
TSV	Taura syndrome virus
TURFs	territorial use rights in fisheries
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations Office for Disaster Risk Reduction
VA	vulnerability assessment
VDS	vessel day scheme
VMS	vessel monitoring system
WACs	West African countries
WB	World Bank
WBC	western boundary current
WCA	Western Central Atlantic
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean

WECAF	Western Central Atlantic Fishery Commission
WECAF–CFRM	WECAF Caribbean Regional Fisheries Mechanism
WEF	World Economic Forum
WESS	United Nations World Economic and Social Survey
WIO	Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association
WMO	World Meteorological Organization
WRI	World Resources Institute
WSSV	white spot syndrome virus
WTO	World Trade Organization
W-W	win-win
Ωar	Aragonite saturation

Chapter 10: Climate change impacts, vulnerabilities and adaptations: Northeast Tropical Pacific marine fisheries

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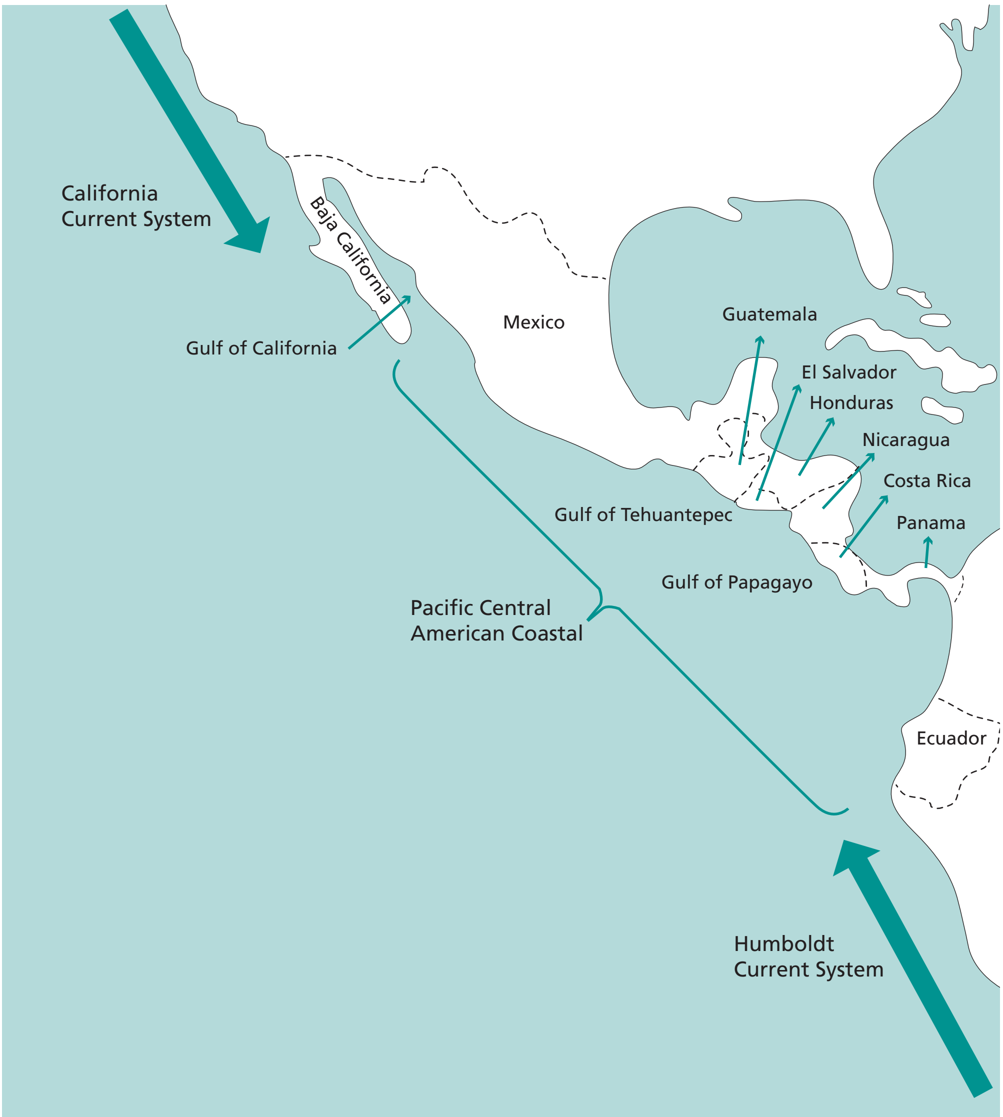
KEY MESSAGES

- Projections of climate change for the region are uncertain in comparison to other regions, particularly regions in higher latitudes.
- Ecosystem impacts:
    - In the extratropical extremes, off Baja California and Ecuador, the major process determining the ocean dynamics is coastal upwelling, for which strong debate exists on how it may respond to climate change.
    - Major threats for the Gulf of California appear to be ocean acidification, hypoxia and harmful algal blooms.
    - In the Pacific Central American Coastal large marine ecosystem (LME), high sensitivity to climate change is related to coastal ecosystems' degradation.
    - Overall, impacts are expected from poleward species shifts and local extinctions, expansion of the globally largest oxygen minimum zone, and coral reef communities suffering from ocean acidification.
- Impacts on fisheries:
    - For small pelagics, interannual changes and multi-decadal trends will likely continue to be the dominant drivers of this fishery during this century.
    - Squid fisheries can be expected to be episodic and opportunistic, with high variability in abundance and availability, which limits the possibility of building long-term sustainable industries based on this group.
    - Although highly uncertain, latitudinal distribution shifts in tuna may affect industrial and coastal fisheries.
    - Impacts in shrimp fisheries may be positive because of better recruitment.
    - Even when small-scale multi-specific fisheries can rapidly adapt to available resources, many of the species on which they depend are highly vulnerable because of critical habitat degradation (coral reefs, mangroves, and saltmarshes).
- Adaptation options for the fisheries sector include improving research, management, planning and policy frameworks (including related technical, administrative, organizational adaptive capacities, and communication). For example:
    - Modelling-based projections should incorporate historical patterns of fisheries and climate variability, and better data.

- The fishing industry may partially cope with climate change by developing sustainable new fisheries, particularly aimed at deep- and mid-water unexploited fish and crustaceans.
- Other actions that would help reduce risk in fisheries would be the full implementation of the *FAO code of conduct for responsible fisheries, the Voluntary guidelines for securing sustainable small-scale fisheries,* and the establishment of information systems aiming to provide early warning of market price volatility.
- Aquaculture as an adaptation option for the region's economy and food security depends on technology development that allows for change between farmed species, the adequate use of genetically improved and robust organisms, and adoption of energy and carbon efficient practices.

FIGURE 10.1
The Northeast Tropical Pacific region and the LMEs falling within it



10.1 INTRODUCTION

10.1.1 The Northeast Tropical Pacific

A total of nine nations share the Northeast Tropical Pacific (NETP) region: Ecuador, Colombia, Panama, Costa Rica, Nicaragua, Honduras, El Salvador, Guatemala and Mexico (see Figure 10.1). While this includes fewer nations than some other regions included in this volume, observed and projected climate trends and their impacts are diverse, partly because of the different potential responses of the main regional oceanographic processes to climate change but also because of the substantial differences in ecological and fisheries-derived characteristics. Based on the analysis of the variability in sea surface temperature, chlorophyll concentration, primary productivity, and fisheries-derived ecological indices, Muller-Karger *et al.* (2017) found strong dissimilarities between the LMEs along the Eastern Pacific (California Current, Gulf of California, Pacific Central American Coastal, and Humboldt), not only in the physical setting, but also in species composition of fisheries landings and the human-related ecological pressures. An implication of this heterogeneity is that information should be disaggregated for, at least, the major subregions to better inform managers and stakeholders about potential impacts, vulnerabilities, and opportunities for mitigation and adaptation.

Multi-annual predictive skills in climate models largely depend on the model capacity to capture accurately the internal (local to regional) features and the external forcing (boundary conditions). For some regions of the world, such as the North Atlantic and the Southern Ocean, forecasts of multi-annual temperature trends have already proved useful for decision-making, even promising at the decadal scale (Tommasi *et al.*, 2017). For the Eastern Pacific, forecasting is intrinsically more limited because of the dominant atmospheric forcing and the timescales at which many of the ocean processes occur. The region is strongly affected by the El Niño-Southern Oscillation (ENSO; for which interannual predictability is very low), but also by extratropical activity from the North Pacific and Atlantic Oceans, and local-to-regional dynamics. In addition, ocean monitoring and large-scale studies are scarce and mostly based on satellite imagery analyses. One major implication is that climate change projections for the NETP are largely uncertain.

10.1.2 Fisheries of the region

The marine fisheries in the NETP include a high diversity of species, fleets and fishing gears; as a consequence of which, societal impacts are also diverse. Small pelagics caught include sardine (*Sardinops sagax*), tropical oil sardines (*Opisthonema libertate, O. bulleri, O. medirastre, Scomber japonicus, Etrumeus teres, Cetengraulis mysticetus, Oligoplites saltus, O. refulgens, O. saurus*), anchovy (*Engraulis mordax*), etc. Most of the production takes place in the upwelling areas of Ecuador and the west coast of Baja California, and inside the Gulf of California, and is caught by industrial fleets, but coastal fisheries resources are also targeted by artisanal fishers. The historical annual maximum production, just for sardine in the Gulf of California, was over 500 000 tonnes in 2008, and over 1.2 million tonnes in Ecuador in the mid-1980s. Jumbo squid (*Dosidicus gigas*) and octopus (*Octopus vulgaris, O. hubbsorum, Octopus* spp.) production exceed 41 000 tonnes per year, over 80 percent of this being jumbo squid. The fishery for this species occurs in oceanic waters, and vessels are adapted from the industrial fleet (for example shrimp trawlers), but an opportunistic coastal fleet also has a prominent and sometimes massive participation that follows pulses in abundance of the resource. Shrimp (predominantly *Farfantepenaeus* spp., *Litopenaeus* spp., *Solenocera* spp., *Sicyonia* spp., but also *Xiphopenaeus* spp., *Trachypenaeus* spp., *Heterocarpus* spp.) is important in seven countries; with a combined average annual catch close to 60 000 tonnes, with most of the production (over 80 percent) coming from the Gulf of California and Gulf of Tehuantepec, both in Mexico. Shrimp fisheries are usually sequential and multi-specific, and take place on the continental shelf near the coast, where industrial and small-scale fleets coexist.

Tuna fisheries (over ten different species) are important for all the countries in the NETP. In recent years, the average yearly production in the region has been around 140 000 tonnes. The largest catches are obtained by industrial fleets operating in oceanic waters, using both seines and longlines, but there are also continuous small-scale operations along the coastlines of the different countries. In general, it is estimated that resource exploitation remains at levels close to the maximum sustainable yield. Sharks; mostly families Carcharinidae (*Carcharinus falciformis, C. limbatus, Prionace glauca,* among others) and Sphyrnidae (*Sphyrna mokarran, S. tiburo, S. lewini*), and rays represented by the orders Squantiniformes (*Squatina califórnica*), Squaliformes (*Echinorhinus cookie*), Hexanchiformes (*Hexanchus griseus*) and Pristiphoriformes (*Pristis perotteti*) (34 000 tonnes), lobster, mainly spiny lobsters (*Panulirus interruptus, P. gracilis, P. inflatus, P. penicillatus, P. argus*); but also other species of Scillaridae (2 744 tonnes), and miscellaneous coastal pelagic fish (52 000 tonnes), are reported as relevant resources in six countries. Other resources such as snappers, mainly genus *Lutjanus* spp. (11 500 tonnes) and various crabs (*Cancer* spp., *Callinectes* spp.) (9 000 tonnes) are relevant in five countries; while molluscs such as gastropods (several genera and species including *Haliotis* spp., *Strombus* spp.) (12 000 tonnes), and bivalves (several families and species, including *Crassostrea virginica, Mercenaria mercenaria, Mya arenaria, Mytilus edulis; Chione* spp.) (9 000 tonnes), and several species of Sciaenids (10 000 tonnes), are relevant in four countries. Other resources considered important in three or less countries are groupers (family Serranidae, mostly *Epinephelus* spp.) (6 500 tonnes), king crab (*Paralithodes* spp.) (5 900 tonnes), sea cucumbers (*Strongylocentrotus* spp.) and other echinoderms (3 700 tonnes), flatfish (several species of the families *Paralichthyidae, Pleuronectidae, Bothidae, Achiridae, Soleidae* and Cynoglossidae) (3 400 tonnes). Catches of the rest of the fisheries are highly multi-specific and carried out by artisanal, small-scale fleets, with different degrees of technological sophistication. In some countries, billfish (*Xiphius gladius, Istiophorus platypterus, Makayra indica, M. nigricans, Kajikia albida, Tetrapturus pflugeri*) (2 300 tonnes) are of great importance for sport fishing, and in some cases also for commercial longline fleets.

In essence, all the above fisheries are subject to some type of control, which varies according to the type of resource but are mostly traditional strategies such as temporal or spatial closures, limited access and quotas. Fishing reserves have recently started to be incorporated. Some resources are considered over-exploited; however, most of the conventional resources in this region are considered fully exploited (FAO, 2016a). In general, all fisheries retain large (e.g. shrimp trawl) or small (e.g. squid) degrees of bycatch. In some cases, these bycatches include threatened species (e.g. sea turtles). Regulations around this issue depend on the target and bycatch species, and the existing scientific knowledge. In some cases, such as tuna purse seiners, gillnets, and shrimp trawls, regulations have succeeded in reducing mortality of threatened species; while for cases such as the fishery for Totoaba (a species of corvina –family Sciaenidae-endemic to the upper Gulf of California), greater efforts are still needed.

The fishers are organized in three general models: individuals, cooperatives and private companies, the latter generally associated with industrial development. Governance in the fisheries sector in the Latin American countries is institutionally organized within the central government. Ministries are responsible for decision-making, and in some cases are supported by a different governmental institution providing technical and scientific knowledge to support the decisions, and defining instruments for regulation and control. These entities are also responsible for implementing control and surveillance actions. In some countries, such as Costa Rica, Ecuador and Mexico, non-governmental conservationist entities interact intensively with the production sector and with government entities, and in some systems assume a bridging role between government and producers. Internationally, the creation of the Central America Fisheries and Aquaculture Organization (OSPESCA) stands out, and established, through the Fisheries and Aquaculture Integration Policy in the Central American Isthmus, a regional framework for fisheries development planning. Highly migratory species, particularly tuna, are evaluated and managed by the Inter-American Tropical Tuna Commission (IATTC).

10.2 OBSERVED AND PROJECTED IMPACTS OF CLIMATE CHANGE ON THE MARINE ENVIRONMENT

The region includes the extratropical Eastern Boundary Currents: the California Current System (CCS) in the north and the Humboldt Current system in the south, both mostly dominated by wind driven coastal upwelling; the Gulf of California, an enclosed sea hosting a large portion of the total Mexican fisheries production (both in volume and value) and the region from the southern part of the Gulf of California to Colombia (the Pacific Central American Coastal LME), where a warm and relatively low productivity coastal system coexists with a highly seasonal group of ocean enrichment systems off the Gulf of Tehuantepec (Mexico), Papagayo (Costa Rica), Panama, and the Costa Rica Dome.

Temperature trends are diverse through the NETP, with the strongest warming occurring off Central America (Lluch-Cota *et al.*, 2013), where several components of the biological communities are already exposed to suboptimal conditions. Hypoxia represents a major issue, as the oxygen minimum layer, lying between the pycnocline and intermediate waters, is remarkable in this region for its size and degree of hypoxia (Fiedler and Lavin, 2017). Ocean acidification may also represent a reason for concern, as projections reveal this is one of the regions more rapidly reaching aragonite limitation for coral reef development under future scenarios. Other indirect effects, such as reshaping of ecosystems and food webs may also prove important.

In the extratropical extremes, off Baja California and Ecuador, the major process determining the ocean dynamics, including surface temperature, oxygen, pH, and primary productivity, is coastal upwelling. Despite being of major scientific interest today, there is still strong debate on how this process might respond to climate change. At the global scale, ocean stratification has increased as a result of the gain of heat in the surface layer, resulting in more wind energy being required to bring deep waters to the surface through upwelling. However, some evidence indicates that wind strength is increasing, at least in some of the major coastal upwelling systems, as a result of the differences in warming rates between land and ocean (Bakun, 1990). Whether wind stress can offset the increased stratification is of paramount importance when projecting climate change impacts in these highly productive systems.

Increased upwelling is expected to enhance primary productivity, and therefore the food that is available to fish. However, the export of organic material from the surface to deeper layers may increase microbial activity and oxygen depletion. Once this water returns to the surface through upwelling, benthic and pelagic coastal communities could be exposed to acidified and deoxygenated water, which would affect marine biota and the ecosystem structure of the upper ocean. Shelf hypoxia conditions have been well documented for some upwelling systems, including the CCS, and even blamed as the potential mechanism shaping the dynamics of the small pelagic species (Bertrand *et al.*, 2011). Another scenario could be that increased primary productivity could sequester carbon and export it to other regions through direct advection and through the movement of pelagic fauna. On the other hand, decreasing upwelling activity would directly limit the productivity of important fisheries, such as small pelagics.

Within the Gulf of California, a positive but slow, long-term warming trend has been reported for the twentieth century. However, when looking only at the last 50 to 60 years, during which time the global surface air temperature series shows the fastest increase, no significant warming trend can be detected and, in fact, the slope is negative (Lluch-Cota *et al.*, 2010). Further, paleo-reconstructions have shown that wintertime temperatures have been similar during the last 170 years. In addition, annual temperature amplitude is highly variable between years, with changes occurring everywhere in the Gulf except for the region around the Midriff Islands. Statistical relationships between these variations in annual amplitude and climate signals have proved to be significant only in ENSO-related processes. Ocean circulation models at the scale of the Gulf, forced with downscaled Intergovernmental Panel on Climate Change (IPCC) scenarios, have resulted in very small differences between future and present conditions, and much smaller than those observed during interannual (ENSO-like) events. Therefore, it can be argued that with the currently existing observations and models, no reliable long-term projection of climate change can be proposed for the Gulf of California, and temperature trends do not show evident threads for the Gulf ecosystem so far.

No reports on acidification of the Gulf of California region exist; however, potential impacts of such a trend, if there is one, could be highly relevant as the region is located at the boundary of aragonite saturation levels, and most of the reefs have been classified as existing within marginal environmental conditions. Therefore, for all the ocean acidification projections based on IPCC scenarios, the Gulf of California is found outside of the suitable habitat. Another reason for concern in this subregion is oxygen. Despite there being very little data, observations of hypoxic or nearly anoxic environments in very shallow water in the southern gulf (less than 100 m depth), and observations of the oxygen minimum zone off the coast of Sinaloa being totally devoid of benthic macrofauna, suggest this may become a critical issue under climate change conditions. Further, massive mortalities of marine organisms inside the Gulf have been associated with harmful algal blooms, and evidence exists from at least one long-term observation effort that the number of toxic species and the frequency and duration of events are increasing.

The major issues in the Pacific Central American Coastal (PCAC) region are closely related to degradation of coastal ecosystems arising from habitat use for aquaculture, tourism, urbanization, pollution, run-off from urban and agricultural lands, and deficient fisheries management. These factors have already increased the sensitivity of the region to climate change related stressors. Biological communities are highly diverse, most fisheries are multi-specific and data deficient, and long-term observations and modelling capabilities are no better than those described previously but, because of its properties, some issues can readily be considered reasons for concern.

The PCAC region exhibits large interannual variability in surface temperature, winds, and thermocline structure. Decadal scale variability is less easily detected, but is evident in some variables, especially those related to the offshore winds at Tehuantepec, Papagayo, and Panama. Long-term climate change can also be detected; over the last century, sea surface temperature has increased by close to 1 °C, and warming is expected to continue, increasing by around 2 °C for a doubling of atmospheric CO_2 (Fiedler and Lavin, 2017); according to the A2 scenario of the IPCC, this two-fold increase could be reached by the year 2080 (Portner *et al.*, 2014). Model projections suggest a shallower but steeper thermocline in the future and, with the increase in stratification, nutrient enrichment of surface waters and phytoplankton production are expected to decrease. Climate change is expected to drive indirect changes in biological communities as a result of poleward shifts in species' distributions and local extinctions, mostly linked to temperature changes. Observations and models are consistent in these trends, more noticeably in the Western Tropical Pacific, but still worrisome for the PCAC.

Surface waters above the pycnocline tend to be nearly saturated with dissolved oxygen. However, off the PCAC, oxygen levels between the pycnocline and intermediate waters are very low, shaping one of the largest and more intense oxygen minimum zones in the world's oceans. Observations indicate that these zones have expanded vertically during the past 50 years, and climate models generally predict further expansion (Fiedler and Lavin, 2017). Great concern exists on the potential impacts for coastal ecosystems.

Another major threat in the subregion is ocean acidification. Today, the lowest surface pH values in the world are now found in the Eastern Tropical Pacific (Fiedler and Lavin, 2017). Further climate change and ocean acidification are expected to impact the reefs in the subregion negatively, as they are already at the environmental limits for reef development.

10.3 EFFECTS OF CLIMATE CHANGE ON STOCKS SUSTAINING THE MAIN FISHERIES

Large-scale models projecting the impacts of climate change in catch potential, mostly based on temperature, oxygen limitation and primary productivity, and neglecting possible synergistic effects of ocean acidification and fishing effort, have shown a reduction of the catch potential in most of the tropical oceans (Pörtner *et al.*, 2014; see also Chapter 4); however, the magnitude of the reduction is less in the NETP than in most of the tropics.

Small pelagic fishes (i.e. sardines and anchovies) captured mostly in upwelling regions off Baja California, Ecuador, and the Gulf of California, are known to react quickly to changes in the ocean climate, showing particularly notorious fluctuations at multi-decadal scales. Regarding temperature, future climate change scenarios have been used to predict a drop of 35 percent in catches of sardines and an increase of anchovy, or increased sardine abundance because of warmer conditions in the California Current. However, ecological change affecting small pelagic species may also include changes in productivity and composition of lower trophic levels, distributional changes of marine organisms, and changes in circulation and their effects on recruitment processes. Further, particularly for the fish populations off the southern NETP, oxygen limitation has been proposed to strongly influence the pelagic ecosystem shape, which is particularly relevant given that the distribution of oxygen in the ocean is changing with uncertain consequences. Other type of models that incorporate historical variability of the environment and catches, indicate that regional climate scenarios would modify slightly the fishery catches and seem unlikely to cause foreseeable breakdowns of natural cycles. These results therefore suggest that as long as no dramatic inflection point is reached in climate, interannual changes of both species and multi-decadal trends will likely continue to be the dominant drivers of this fishery during the current century (Lluch-Belda *et al.*, 2013).

The squid fishery is relatively new in Mexico and only starting in Ecuador, and therefore there is limited knowledge on its long-term dynamics. Evidence indicates that jumbo squid can dramatically and extremely rapidly change its latitude distributions. At the same time, it is very plastic in terms of diet, respiration, vertical distribution (even through the oxygen minimum zone), and reproduction, which makes it a highly resilient group to changing environment. However, this same ability to change distribution and habits makes the fishery highly unpredictable. The expected impacts of climate change could therefore be the episodic development of opportunistic fisheries, with reduced possibilities to build around long-term sustainable industries.

For tuna and tuna-like fisheries, impacts of climate change have been proposed to be similar to those observed during some of the El Niño events, although this is highly uncertain. Divergent responses of yellowfin tuna catches at different locations show that the principal impact of ENSO on tunas is on their regional redistribution.

The warming of surface waters and the decline in primary productivity could result in a redistribution of tuna resources to higher latitudes or areas where the ocean productivity has been less or not affected. This could result in changing migration patterns, forming more dispersed and less numerous schools, which would negatively affect fishing operation costs and yields.

Impacts on shrimp fisheries are also uncertain. In general, warmer waters and increased rainfall during warm events (i.e. El Niño) favour the reproduction and recruitment of shrimp populations, and fisheries are favoured. There could also be some degree of poleward expansion into more productive systems. The ways in which fisheries operate would change, such as bycatch reduction, sharing catches between industrial and artisanal fleets, among others, but these have not been analysed.

Small-scale, coastal multi-specific fisheries could be seen as highly resilient, because they can rapidly adapt to changing target species, market preferences, and location of new fishing banks. Furthermore, redistribution of fishing camps may be faster and easier than relocation of large-scale industrial fisheries infrastructure. However, these small-scale fisheries are highly sensitive because many of the most important species are more or less dependent on coral reefs, mangroves, and seagrasses, which are vulnerable and in some cases already threatened ecosystems. Also, non-industrialized fishers are more closely dependent on short-term income, their capacity to influence markets is more limited than well-organized, large-scale industries, and management and enforcement are more complex.

10.4 IMPLICATIONS FOR FOOD SECURITY, LIVELIHOODS AND ECONOMIC DEVELOPMENT

At the local to regional levels, an important segment of the societies from the nine countries is highly dependent on fisheries. Industrial fisheries represent, for some regions, a major economic activity and impacts of climate change could affect these industries. However, by far the largest number of people dependent on fish is located in the small-scale fisheries, which is also a more sensitive sector because of higher poverty levels, and reduced access to alternative economic activities.

Poverty undermines the resilience of social-ecological systems such as fisheries. A combination of climate-related stresses and widespread over-exploitation of fisheries reduces the scope for adaptation and increases risks of stock collapse (Allison, Beveridge and van Brakel, 2009). It is clear that fishing pressure has already imposed significant problems on several coastal multi-specific fisheries across the NETP countries, mostly because management faces serious limitations in terms of technical information and permanent, reliable monitoring programmes. In addition, the management strategies are much less developed than those for industrial fisheries, and the lack of communication, enforcement, and potential for participation in co-management schemes make the adoption of such strategies by small-scale fishers virtually impossible.

Adaptive institutions and new management strategies would increase the capacity of ecosystems and people to accommodate future changes and conditions. Strengthening adaptive governance and reducing vulnerability are both mutually reinforcing and synergistic with building capacity to adapt to climate change. Adoption of better management practices, including increasing technical and scientific capacity, communication and participatory strategies, and strengthening institutional arrangements, are the best adaptation options for small-scale fisheries under a changing climate. These and other adaptation options are discussed further in Section 10.6 below.

10.5 VULNERABILITY AND OPPORTUNITIES FOR THE MAIN FISHERIES AND THOSE DEPENDENT ON THEM

The region includes the Pacific coast of Ecuador, Colombia, Panama, Costa Rica, Nicaragua, Honduras, El Salvador, Guatemala, and Mexico, covering 35° in latitude, three large marine ecosystems, and tropical and subtropical climatic regions. Most important industrial fisheries target small pelagics, mostly sardines and anchovies, jumbo squid, tuna, and shrimp. Small-scale fisheries occur along the entire coast, partly based on the same resources exploited by industrial fleets, plus a high diversity of fish, molluscs and crustaceans.

Large-scale models projecting the impacts of climate change in catch potential have shown a reduction of the catch potential in most of the tropical oceans, with a relatively smaller reduction in the NETP (Cheung *et al.*, 2009; Pörtner *et al.*, 2014; Chapter 4). However, this is one of the world ocean regions where climate and oceanographic models are more limited, and therefore climate change projections are highly uncertain. Also, the diversity of species and fisheries makes it impossible to make a single, general assumption on the potential effects of climate change on regional fisheries. Modelling-based projections should incorporate historical patterns of fisheries and climate variability, and better data.

Major environmental reasons for concern are 1) temperature trends, particularly off Central America; 2) deoxygenation, as the region already lies within the largest area of the world ocean with severe hypoxia; and 3) ocean acidification, as projections reveal this is one of the regions more rapidly reaching aragonite limitation for coral reef development under future scenarios. Potential impacts on major fisheries are: for small pelagic fishes, interannual changes and multi-decadal trends which will likely continue to be the dominant drivers of this fishery during the remainder of this century. Squid fisheries can be expected to be episodic and opportunistic fisheries, with reduced possibilities to develop long-term sustainable industries. Although highly uncertain, latitudinal distribution shifts in tuna may affect industrial and coastal fisheries, and impacts on shrimp fisheries may be positive thanks to better recruitment.

Although small-scale fisheries may appear to be relatively resilient because they can rapidly adapt to changing target species, market preferences, and location of new fishing banks, major consequences for livelihoods can be expected because many of the targeted species depend on threatened ecosystems (coral reefs, mangroves, and seagrasses), and fishers are more closely dependent on short-term income, their capacity to influence markets is more limited than that of well organized, large-scale industries, and management enforcement is more complex.

10.6 RESPONSES AND ADAPTATION OPTIONS

Fisheries governance and regulations (i.e. harvest control rules and incentives driving fisher behaviour) partly determine the socio-ecological resilience of the sector to climate change impacts. However, there is yet no recipe for a regulatory regime that can clearly increase fisheries resilience (Ojea *et al.*, 2017). For the small-scale fisheries, adaptation options include improving technical, administrative and organizational aspects of fisheries management and the social education of the fishers. This should promote development of organizational mechanisms such as integrating value chains and training for diversifying fishing activities (Flores-Nava, 2010).

To some extent, industrial fisheries have already been dealing with changes in resource availability because of having to cope with natural climate variability. The adoption of policy initiatives and management measures for reducing vulnerability in the fishing sector could benefit from the lessons and strategies learned by fisheries that have successfully managed change by incorporating environmental stress factors into their strategies.

Global circulation models are the only tool that is available today for estimating the effects of climate change on fisheries, so their deficiencies when representing regional processes (e.g. upwelling), reduce the possibility of generating plausible future scenarios of the environment and its influence on fish production. This is particularly critical in this region. Incorporation of historical patterns of fisheries and climate variability, and more intense data collection, including systems for ocean monitoring, could increase significantly the accuracy of climate and ecological models (Lluch-Cota *et al.*, 2017).

In order to sustain economic and social benefits to the fishing industry facing climate change impacts, one option may be the sustainable development of new fisheries based on currently under-exploited resources. This seems feasible in the region because of the existence of known deep and mid-water unexploited populations of fish and crustaceans, such as hake and giant king crab.

In terms of adaptation, the full implementation of the *FAO code of conduct for responsible fisheries* (FAO, 2016b) and the *Voluntary guidelines for securing sustainable small-scale fisheries* (FAO, 2018), may prove to be the best strategy. Precautionary approaches are recommended, particularly measures to reduce levels of fishing mortalities, especially in populations currently at maximum exploitation rates and over-exploited. Moreover, the industrial and coastal fisheries sector is likely to face the challenge of moving from one fishing site to another as well as changing target species. To carry them out successfully, these challenges imply the development of better organizational skills in order not to exceed extraction efforts beyond the stock's replacement capabilities in a changing environment. In addition, national and multilateral agreements enabling the mobility of fleets should be promoted, considering also the legal change of target species, as required, and governmental support for purchasing more efficient equipment.

Another recommendation refers to the establishment of information systems aimed at providing early warnings of volatility in market prices. Market warnings would allow rapid adoption of strategies that may include creating specific funds, extending insurances coverage, incorporating probabilistic analysis to risk management, and considering uncertainty during the planning of the sector's activities.

One major option to mitigate the adverse impacts of climate change on marine fisheries is aquaculture, the fastest growing food production sector and with the potential to contribute significantly to the region's economy and food security. Apart from Ecuador and Northwest Mexico, which host important shrimp farming enterprises, marine aquaculture based on different species still has great development potential in the NETP. However, for aquaculture to become an effective climate change adaptation option, two major challenges should be addressed. One is that reared species, for which technology development may take several years, may face suboptimal physiological conditions under future climate (especially temperature). Secondly, that increasing the use of waterbodies and coastal areas for culture, together with the direct impacts of climate change, may increase the outbreaks of known and new pathogens or parasites. Therefore, the ability to change between farmed species, and the adequate use of genetically improved and robust organisms, should become a major technological priority. Further, to represent a sustainable option for food production, aquaculture will also face the challenge of rapidly becoming a more energy and carbon efficient practice (Sae-Lim *et al.*, 2017) and less reliant on capture fisheries for feed.

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This FAO Technical Paper is aimed primarily at policymakers, fisheries managers and practitioners and has been prepared particularly with a view to assisting countries in the development of their Nationally Determined Contributions (NDCs) to the Paris Climate Agreement, the next versions of which are to be submitted by 2020. The Technical Paper provides the most up-to-date synthesis on the impacts and risks of, and the opportunities and responses to climate change in the fisheries and aquaculture sector, in the context of poverty alleviation.

It covers marine capture fisheries and their environments (Chapters 4 to 17), inland waters and their fisheries (Chapters 18, 19 and 26), as well as aquaculture (Chapters 20 to 22). The Technical Paper also includes chapters on disasters and extreme events (Chapter 23) and health and food safety hazards (Chapter 24). Guidance and tools are presented for planning and implementing effective and explicit adaptation (Chapter 25), while taking into consideration the impacts on fisheries and aquaculture of potential adaptations to climate change in other sectors (Chapter 26). Mitigation is addressed in Chapter 27, which provides quantitative information on the fisheries and aquaculture sector's contributions to greenhouse gas emissions, as well as strategies and tools for mitigation.

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