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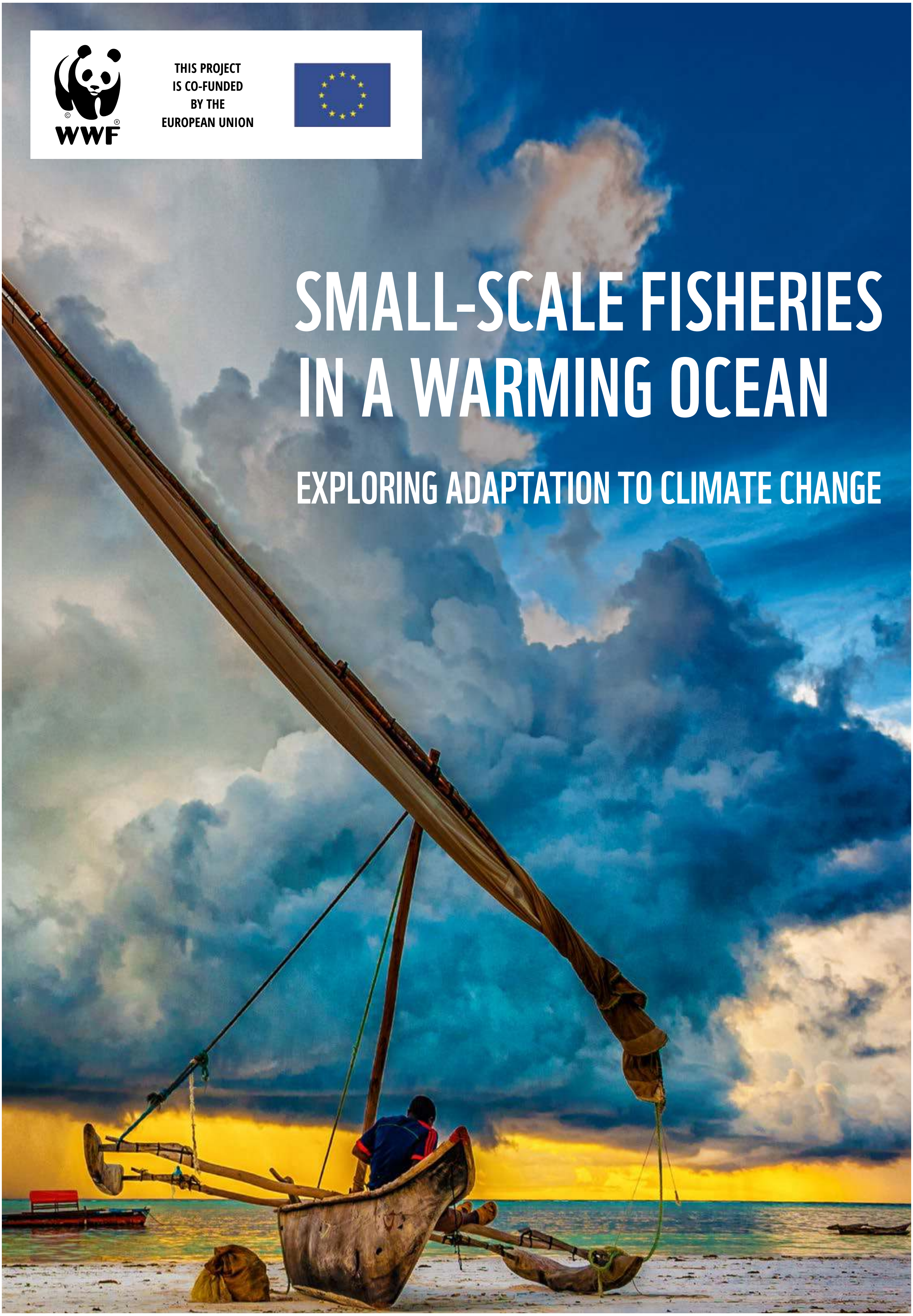
SMALL-SCALE FISHERIES IN A WARMING OCEAN

EXPLORING ADAPTATION TO CLIMATE CHANGE



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For more information please visit the Fish Forward website: **www.fishforward.eu**. This study was produced under the lead of Agrocampus Ouest (France), in collaboration with the University of British Columbia (Canada), the National Fisheries Institute (Ecuador) and the Charles Darwin Foundation (Galapagos). Its contents are the sole responsibility of WWF and do not necessarily reflect the views of the EU.

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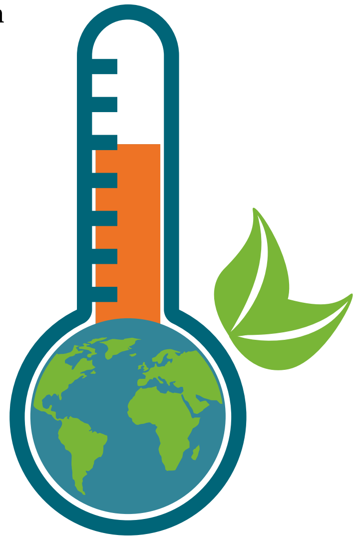
SUMMARY



Global warming, caused by the increase of greenhouse gas (GHG) emissions through human activities, has a strong impact on our oceans including changes to oceanographic characteristics, as well as to abundance and distribution of marine life. Moreover, it also has severe socio-economic impacts on people living at and from the sea. In order to predict and evaluate the impacts of global warming (and subsequently to find suitable adaptation strategies), scientific computer models are utilized. These climate change models predict the effects of global heating on marine life and associated fisheries on a global scale, but often with a high level of uncertainty and low geographic resolution. This makes it difficult to determine effective adaptation measures for fisheries on a local level. The development of adaptation and mitigation strategies is especially urgent in small-scale fisheries that contribute about half of global fish catches and make an important contribution to nutrition, food security, sustainable livelihoods and poverty alleviation, especially in developing countries.

This study used a comprehensive conceptual framework that integrates different formats of knowledge, and an interdisciplinary research approach illustrated by the integration of both, the natural and the social sciences traditions. Our study aimed to explore local adaptation measures of fishers and fishing communities by complementing fine-grained scientific climate model predictions with insights based on the perceptions, knowledge, and practices local fishers have about climate change. This combined approach represents an innovative lens to understand climate change and human adaptation since it merges both predictive (computer models) and social sciences (traditional and local knowledge of fishers). We believe it will enhance our ability to promote and strengthen the natural capacity of adaptation of fishers and fishing communities with the aim to promote and support adaptation strategies of small-scale fishers.

First, the modelling aimed to predict the climate change impacts on commercial fish species and their distribution in three case countries (Ecuador; mainland and Galapagos Islands, South Africa and the Philippines). These models were based on multitemporal data sets for the areas where the study took place, designed by using outputs of the IPCC scenarios and risk analysis methods. This allowed us to identify some of the anticipated impacts of climate change on the currently exploited fish stocks in those countries.

The second part of the study aimed to i) explore local perceptions by fishers, of the effects of climate change on small-scale fisheries, ii) describe how well prepared the small-scale fishing sector is in front of climate change, and iii) illustrate the adaptation measures, capabilities, challenges, and actions, carried on by fishers, to cope with climate change. We organized four workshops (in the same three case countries) involving varied and relevant sectors and actors, within the small-scale fisheries sector. The workshops were attended by fishers, researchers and managers and exhibited diverse formats, based on the location's and fisheries sector characteristics.

Global heating has impact on most of the main fish species exploited by small-scale fishers

Our fine-grained climatic models showed that global heating is expected to have significant adverse impact on most of the main fish species exploited by small-scale fishers in the case countries, even if global warming is limited to 2°C (being the best-case scenario). Most considered fish species exhibit a medium or high risk to suffer from climate impacts and many of them will be outside their maximum preferred temperature within a few decades. That will ultimately lead to a decrease in biomass by -5 to -20%, depending on species and scenarios. However, our models did not include a range of climate heating effects, such as the complete loss of essential fish habitats (ex. coral reefs) that will have severe additional devastating effects on the local ecosystems. It must also be noted that some of the produced models illustrated trends but could not be fully precise (i.e., Galapagos' case), due to high systems' dynamics and rather scarce availability of information on some of the commercial fish stocks.

In our models, species composition of the catch is also expected to change, notably in Ecuador and South Africa, where the small-scale fisheries are currently targeting a large diversity of fish. As for the Philippines, the handline tuna fishery emerges as the most at-risk under the worst-case scenario for this country, where a large decrease in catches are expected and where those catch losses can not be compensated by switching to other target species.

The results of the 'local/traditional knowledge' part show that small-scale fishers are already experiencing strong effects of climate change, entailing serious socio-economic consequences in communities that are often already struggling with low incomes. The most frequently mentioned signs of climate change observed by fishers includes abnormally warm seawater temperatures. In some seasons and in some areas, fishers reported an increased frequency and severity of extreme events such as high tides or strong winds. In all three countries

Fish landing site in Puerto Lopez, Ecuador workshop participants experienced decreases in fish availability, either due to a decrease in fish abundance or changes in their distribution (further offshore and/or deeper). Fishers also highlighted changes in the health of ecosystems, notably with coral reefs being degraded or already dead, which is a matter of great concern. Socio-economic consequences highlighted by the fishers were lower incomes, caused by fewer fish and personal safety concerns, due to the increased difficulty of finding fish and/or caused by more frequent extreme sea conditions. The common point among participants of the four workshops, was in fact, that effects of climate change were considered 'a source of great concern' and the dominant feeling of participants was that the fishery sector is not yet ready to adapt.

General adaptation measures highlighted by the participants of the workshops included: i) better and more effective monitoring and control of fishing activities, ii) setting up participative structures to better involve all relevant actors during consultation and/or decision-making processes, iii) improving the quality and thus the value and better commercialization of fish products, iv) better information, education and communication, v) the implementation of modern technologies and the use of effective fishing gear and equipment, vi) more research on fisheries resources, and vii) alternative economic incomes for fishers (both fishermen and fisherwomen). Our study found that small-scale fisheries in the four case studies analyzed, are not yet ready to face climate change and its expected effects on marine resources and fishing activities. We identified specific recommendations in the different study areas to improve fisheries management, and governance policies and practices, according to the six key objectives needed to achieve the ecological and economic sustainability of the small-scale sector in the context of climate change. Specifically, these six objectives aim to make the fisheries management and governance more: 1. responsible and efficient, 2. adaptive, 3. participative and collaborative, 4. science-based, 5. precautionary, and 6. social (including gender equity).

Main findings of this initiative show that the resilience of a socio-ecological system heavily depends upon the adaptation potential of the human community, and more broadly, the whole country. Small-scale fishers (men and women) in our three study areas, often live in low income communities (with the exception of Galapagos, where the average basic wage is almost two times the one in Ecuador mainland). This means that adaptation mechanisms entail high costs (e.g. associated to the need to go out further to find fish, changing gear, investing in science, controls or capacity building, building safer harbors or landing sites) which often are or would be the cause and consequence of indebtment and bankruptcy. Reducing poverty and supporting the population with basic living conditions are a guarantee of better adaptation. Fishers were aware of climate change and its importance in affecting their resources. However, there is still much to be done urgently to warrant and ensure better living conditions (i.e. health, education, sanitary conditions and basic services) that will in turn increase the level of resilience of people and free capacities to utilize natural resources in a sustainable way and to support the health of local ecosystems, especially in the light of climate change.

Fishers perceive already now the effects of climate change

INTRODUCTION – AIM OF THE STUDY

The latest projections warn us that climate change will have disastrous impacts on marine ecosystems and dependent fisheries (IPCC 2019). These conclusions come from several scientific models predicting the effects of climate change on the future of fisheries on a global scale. Unfortunately, these models often display a high level of uncertainty and have a low geographic resolution. Additionally, social and human driven variables are hardly integrated into such models, which results in these social dimensions to be overlooked. This makes it challenging to propose concrete adaptation recommendations at local level (Holsman et al. 2019), especially for small-scale fisheries that will probably be hit hardest with catches that are globally expected to decrease and become more variable under the impact of anthropogenic climate change (IPCC 2019).

As climate change is currently already impacting distribution and abundances of several fish species (IPBES 2019), there is an urgent need to better understand how to activate adaptation measures at present time. One way to explore and determine local adaptation measures, is to complement fine-grained climate model predictions with perceptions and knowledge of fishers themselves regarding the observed changes in their environment. This combined approach merging predictive science with traditional knowledge aims to help foster and optimize adaptation strategies, especially in the fisheries that will face the hardest conditions (i.e. small-scale in areas of high impact).

In this study, we first modelled the predictions of climate change impacts on fish distribution and catch based on the outputs of the IPCC scenarios of climate change and by using risk analysis methods. This was achieved for representative small-scale fisheries in three major fishing countries: Ecuador (mainland and Galapagos Islands), South Africa, and the Philippines. In a second step, we determined through workshops how small-scale fishers and other stakeholders in those countries perceived the impacts of climate change based on local knowledge, and evaluated the capability of those fisheries to adapt to climate change. Under the sociological terms, local and traditional knowledge, define how the relationships between humans and objects are. This idea follows Berger and Luckmann's perspective on the dialectical relationship between 'objective' and 'subjective reality', constructed through the employment of different knowledge. Additionally, it relies on Foucault's claim about 'discourses as practices of power/knowledge', understanding 'practices' as conventionalized patterns of action, based on collective stocks of knowledge about the 'proper' way of acting (Keller 2011a, 2011b). Within the frame of this study, the relation between fishers and fish gets deeply influenced by how fish has been made sense of, by fishers and by fishing communities, under the 'subject-object' notion, over the period of decades, centuries or millennia, depending on the location of the sites within this study. In that context, the local/traditional knowledge about fishing and the practices related to this activity, become key at defining the adaptation strategies and/or mechanisms to cope with the change driven by climatic variations. In our study we identified the key challenges those fisheries will specifically have to face, and the knowledge or perceptions the different stakeholders have on climate change. Thus, considering "what science says and what fishers know", this report aims to identify effective strategies for adaptation and to make significant recommendations regarding fisheries management and the fishing activity itself, in order to improve capacities of the fishers themselves to face the expected impacts of climate change.

More specifically, in each case study we studied:

1. Climate change modelling: we explored the vulnerability and the risk of impact linked to climate change for different important commercial species in the case studies' fisheries.

2. Knowledge & perceptions: we highlighted and gathered information on the perceptions the fishing sector stakeholders (women and men from fishing communities, fishers, associations, scientists, people from government) regarding climate change (traditional knowledge, experiences, awareness, academic expertise, adaptation measures), by developing workshops with the stakeholders of the small-scale fisheries. These workshops aimed at:

    a. **What do we know?** Explore and understand perceptions, knowledge and needs of the small-scale fisheries sector, in order to examine and identify effective climate change adaptation strategies to adapt to climate change and/or regional climate variability affecting countries' fisheries.

    a. **How to adapt?** Identify existing and potential future practices, tools and strategies, used by small-scale fishing communities, to adapt to the local/regional climate variability and promote sustainable fisheries management and sustainable consumption at national and international level (e.g. linking targeted fishing exported to and consumed as a commodity in the European Union markets).

    a. **How to implement?** Explore potential pathways to integrate considerations for small-scale fisheries in the national climate change adaptation policies, with the involvement of local governments and other stakeholders.

This report eventually aims to deliver decision makers and fisheries stakeholders community-based information and scientific data inputs (i.e. knowledge) to develop regional and national adaptation strategies and proactively implement effective adaptation and mitigation measures, in the face of climate change.

Chapter 1 introduces the general context of the study, summarising the main changes and impacts on fisheries expected worldwide from climate change, introducing the existing and recommended tools for adaptation, and presenting the three case studies. In **chapter 2** (modelling approach) we estimate the vulnerability and the risk of climate change impacts on the most important species in the fisheries of the three case studies. **Chapter 3** (knowledge and perceptions) is dedicated to fishers' perceptions and to the identification of potential adaptation strategies, integrating the main findings of the workshops organised in Ecuador (mainland coast and Galapagos Islands), South Africa and the Philippines. **Chapter 4** presents the main recommendations arising from this study in terms of adaptation to climate change of both the small-scale fishing activities and the fisheries management. The extended materials and methods of Chapters 2 and 3 can be found in the **Annex** report.

Local fish market in Catanduanes, Philippines

1. GENERAL CONTEXT
SCIENCE AND SCIENTIFIC KNOWLEDGE

1.1. Climate change and its impact on fisheries

"Climate change refers to a change in the state of the climate that can be identified (e.g. by using statistical tests and climate models) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer" (IPCC 2018). To date, human-generated emissions of greenhouse gases since the start of the Industrial Revolution have led to global warming of the air of 1.1 °C (WMO 2019). If these emissions continue at current rates, we are likely to reach 1.5 °C of warming between 2030 and 2052 – an additional warming of 0.4 °C from today's level (IPCC 2018).

Observed and expected impacts of climate change on oceans

Oceans absorbed 28% of the CO_2 emitted through human activities

The oceans have absorbed approximately 28% of the carbon dioxide emitted through human activities and more than 90% of the added heat since the 19th century. As a result, ocean variables are changing (Gattuso et al. 2015). During the 20th century, sea-surface temperature (SST) increased on average by 0.07 °C per decade and ocean pH decreased by 0.1 since the Industrial Revolution (Stocker et al. 2013), while oxygen content has decreased by more than 2% since 1960 (Schmidtko et al. 2017). These changes are projected to exacerbate under the business-as-usual/high greenhouse gas emission scenario (called the Relative Concentration Pathway-RCP 8.5 scenario, according to IPCC), while the changes will be substantially limited by a strong-mitigation scenario (RCP 2.6) (IPCC 2019; Gascuel & Cheung 2019; Gattuso et al. 2015).

Climate change also induces an acceleration in the rise of sea-level (Nerem et al. 2018; WMO 2019). There is a high certainty that the sea level will rise to some extent in 95% of the oceans by the end of the century (IPCC 2019). The two major causes of a global rise in sea-level are thermal expansion of the oceans (water expands as it warms) and the increased melting of glaciers and sea-ice. Sea-level rise is of high concern and importance for coastal systems as it could lead to storm surges, coastal flooding, coastal erosion and salinisation (IPCC 2019).

Phytoplankton production is the process at the base of the marine food web, controlling through bottom-up mechanisms the energy and food available to higher trophic levels[1] and ultimately to fish. Change in primary production is an indicator of changes in light, temperature and nutrients. In tropical marine ecosystems, warmer conditions may reduce the abundance and primary productivity of phytoplankton. This decrease results from enhanced

1 The trophic level of a species defines its place within the food web. By definition, primary producers (i.e. phytoplankton, algae…) are at trophic level 1, their predator (i.e. first order consumers including small zooplankton, herbivorous fish or invertebrates…) are at trophic level 2, their predators at trophic level 3, etc. The trophic level of our studied species is provided in Table II.3, from FishBase (Froese & Pauly 1994)

stratification, less vertical mixing and reduced nutrient supply to the euphotic zone[2] (Gittings et al. 2018). Based on the most recent understanding of tropical ocean primary production, it is estimated that global marine primary production will decline from 3 to 9% by 2100 (Kwiatkowski et al. 2017). On a global scale, a decrease of 8.6% (+/-7.9%) is projected under the highest emission scenario (e.g., RCP 8.5) and a decrease of 2% (+/-4.1%) under the high mitigation scenario by 2090 (e.g., RCP 2.6), with large regional variability (Bopp et al. 2013; FAO 2018).

Trends resulting from climate change models have to be considered cautiously, as the magnitude of predictions might show some level of uncertainty (Payne et al. 2016). In addition, global trends can mask local variability, with expected local changes that are even larger than the mean, depending on the region. Recently, the IPCC also underlined the importance of short-term variability and extreme events due to climate change. In particular, frequency and intensity of marine heat waves (Frölicher & Laufkötter 2018) is expected to increase and might be the most important change occurring in the ocean.

These impacts will have significant consequences for ecosystem structure and functioning, but also for goods and services associated with these ecosystems (food provision from fisheries and aquaculture, oxygen production, carbon storage) (FAO 2018; Thiault et al. 2019; WMO 2019).

Observed and projected impacts on abundance and distribution of fish and invertebrates

The physiology, biology (including reproduction and growth), ecology or behavior of all marine organisms are sensitive to sea water temperatures and to other parameters affected by climate change such as oxygen content or acidity (pH). Thus, climate change is expected to impact marine resources and associated fisheries (FAO 2018; Gascuel & Cheung 2019).

Observation shows that marine species are already reacting to ocean warming by shifting their latitudinal range and/or depth range, towards colder, deeper, further offshore or polar waters (Pinsky et al. 2013). Organisms follow their thermal optimum, and this leads to global range shifts towards higher latitudes and range retractions at equatorial boundaries. Expected range shifts of different fish species could vary between 30 and 130 km per decade towards the poles, and 3.5 m per decade into deeper waters (Cheung et al. 2010; Cheung 2018).

2 The layer of sea water that receives enough sunlight for photosynthesis to occur

Climate change is thus causing large-scale changes in marine biodiversity, both in terms of species biogeography and phenology[3] (FAO 2018; IPBES 2019). The most important changes are expected in polar regions due to a massive arrival of temperate fish. Conversely, tropical zones are likely to see a number of local extinctions higher than the world average, extinctions that might not be compensated by species coming from warmer waters and hence a reduced biodiversity in these areas.

Modifications of species compositions will have an impact on predator-prey relationships, thus affecting the functioning of trophic networks (Du Pontavice et al. 2019) and recruitment[4] of commercial species. Britten et al. (2016) showed fish recruitment levels are already decreasing by 3% per decade on a global scale.

As not all species are moving towards poles at the same speed, or are not as sensitive to warmer temperatures in the same way, some matches/mismatches are expected in the timing of prey and predators that will adapt to local or regional changes in ocean temperature. Poloczanska et al. (2013) showed for instance that the seasonal shift induced by climate change should differ between the reproduction and larvae hatching of many fish species, and the production of zooplankton feeding those fish larvae.

Physiology and ecology of marine species are also expected to be affected by the acidification and decrease in dissolved oxygen concentration of the ocean. The decrease in oxygen concentration should affect the survival, reproduction and growth of numerous species, as well as their vertical distribution and resistance to diseases (Breitburg et al. 2018). Acidification also has physiological impacts on certain groups of marine organisms (calcification, growth, larval mortality, behaviour). This affects especially the calcifiers (e.g. shellfish) in natural environments (Seggel et al. 2016; IPCC 2019), as acidification obviously alters the fixation of calcium carbonate (CaCO3) in skeletons or shells of organisms.

Marine heat waves are expected to have a major impact on coastal ecosystems

The most recent IPCC report (2019) shows that the most significant effects on living organisms will also be linked to extreme events. In particular, marine heat waves should become more intense, longer and above all more frequent (Frölicher & Laufkötter 2018; IPCC 2019). They are expected to have a major impact on coastal ecosystems, inducing high mortalities in certain species and consequently modifying the assemblages of species and the functioning of food webs (Frölicher 2019). Effects are expected to be amplified along food chains with particularly significant impact on predators, and consequently on the resources exploited by fisheries (Chust et al. 2014; Lotze et al. 2019). Marine habitats essential for fish, such as kelp forests, seagrass beds and coral reefs will be particularly affected (IPBES 2019; IPCC 2019).

3 Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate, as well as habitat factors.

4 In fisheries, recruitment refers to the number of fish surviving to enter a fishery. These fish have to pass through a number of life history stages (e.g., egg, larva, juvenile, etc.) before becoming vulnerable to fishing gear.

Increase in sea water temperature, intensification of marine heat waves and acidification have cumulative effects on coral reefs, already causing massive coral bleaching. IPBES (2019) considers that 50% of the world's coral reefs have already been destroyed compared to the pre-industrial period and that only 1% is expected to survive until 2050 in the case of a strong-mitigation scenario (RCP 2.6, see **Annex** report). This will, of course, have dramatic consequences for humans, especially as coral reefs are home to 25% of all marine life, and more than a quarter of the world's small-scale fishers depend on them for their livelihoods (FAO, 2018).

More generally, climate change should decrease the global fish biomass by as much as 30 to 40% in tropical regions by 2100 (under RCP 8.5), because of changes in primary production and an increased natural mortality due to changes in temperature (Carozza et al. 2019; Lotze et al. 2019) (Figure I.1). Ecuador, South Africa and the Philippines – the three case studies we are exploring – are all within red areas (from light to dark red), highlighting that adaptation measures are thus urgently required there.

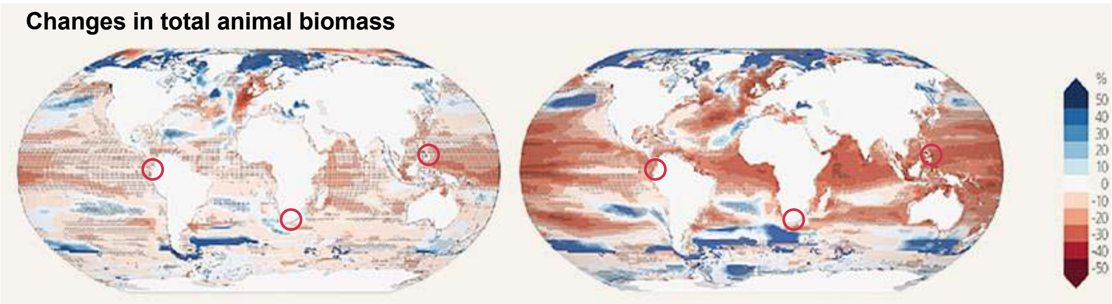


Figure I.1 – Projected changes in total animal biomass for selected ocean regions under low (left) and high (right) greenhouse gas emission scenarios. Blue means an increase in biomass, from 10 to 50% (light to dark blue), red means a decrease in biomass from 10 to 50% (light to dark red) (Lotze et al. 2019). The red circles highlight the three case countries selected for this study.

How marine species are being impacted by sea water warming and ocean acidification depends on their level of vulnerability i.e. to differences in the species' sensitivity, adaptive capacity and exposure to climate hazards. Studies showed that species' response to climate impacts vary depending on their respective biological traits (Dawson et al. 2011). Empirical and theoretical studies across taxonomic groups identify general attributes that predispose species to being vulnerable to the effects of climate change (e.g. Okey et al. 2015; Hare et al. 2016). Species with broad physiological tolerances, such as those accustomed to large climatic variations may be more likely to persist in their current habitat or range extent. Traits that influence a species' ability to disperse (such as the mode of dispersal), duration of larval phase or fecundity, may further affect the capacity of a species to move away from prohibitively altered environments into more suitable ones.

Consequences of climate change for fisheries and their socio-ecological risks and vulnerabilities

Changes in the oceans have impacted marine ecosystems and ecosystem services with regionally diverse outcomes, challenging their governance (FAO 2018). Many negative impacts of climate change are expected for food security, local cultures and livelihoods, and for tourism and recreation. These impacts on ecosystem services already have negative consequences for the health and well-being of indigenous people and local communities dependent on fisheries (Golden et al. 2016; IPBES 2019).

Climate change is expected to modify the fisheries production patterns due to changes in species distribution and abundance (Quaas et al. 2016). Thus, climate change can significantly alter the availability and composition of commercial fisheries' catches (Cheung et al. 2010; Cheung et al. 2013b), thereby having socio-economic implications for fishers, markets and consumers worldwide (Blanchard et al. 2017; Thiault et al. 2019). Even more worrying, is the fact that global demand for fish is expected to increase in the coming years because of human population growth (FAO 2018).

The signature of ocean warming on global fisheries' catch was notably studied through the Mean Temperature of the Catch (MTC), that is calculated from the average inferred temperature preference of exploited species weighted by their annual catch (Cheung et al. 2013b). Results show that, on a global scale, MTC increased at a rate of 0.19 °C per decade between 1970 and 2006 and non-tropical MTC increased at a rate of 0.23 °C per decade. Changes in MTC in 52 large marine ecosystems are significantly and positively related to regional changes in sea surface temperature.

Hook and line fisher, Philippines

The changes in fish distribution and abundance are likely to induce a global redistribution of the Maximum Catch Potential (MCP) of the different fishing areas (Figure I.2). By 2050, total maximum catch potential in the world's exclusive economic zones (EEZs) (excluding those bordering semi-enclosed seas) is projected to likely decrease under climate change by 3 to 5% if the Paris Agreement (signed in 2016) objectives are reached, and by 7 to 12% if a "business-as-usual" greenhouse gas emission scenario is met (FAO 2018; IPCC 2019). In this last scenario, the projected decrease in catch varies by 16 to 25% by the end of the 21st century. Although there is variability in their predictions, all models agree on the timeframe and magnitude of catch reduction. A main reason for the high level of agreement between the two models is that changes in potential catches in both models are strongly driven by changes in plankton productivity.

All models also indicate there will be winners and losers (Barange et al. 2014; IPCC 2019). By 2050, catches could increase close to the poles, while in the intertropical zone these could decrease by up to 40% in some areas, thus having a large impact on countries highly dependent on fisheries as a source of protein. As fish are also crucial sources of micronutrients to humans and mainly coastal communities strongly relying on fisheries, declines in fish populations over the coming decades are predicted to cause micronutrient and fatty-acid deficiencies for more than 10% of the global population, especially in the developing nations at the Equator, i.e. equatorial, tropical mid-latitudes (Golden et al. 2016). Tropical zones will be hit hardest by these changes, given that in these regions the largest number of people are reliant on marine resources for their livelihoods. They are at the same time socially and financially least able to adapt and prepare for this. This poses additional risks to food security and health for fishery dependent people in tropical zones.

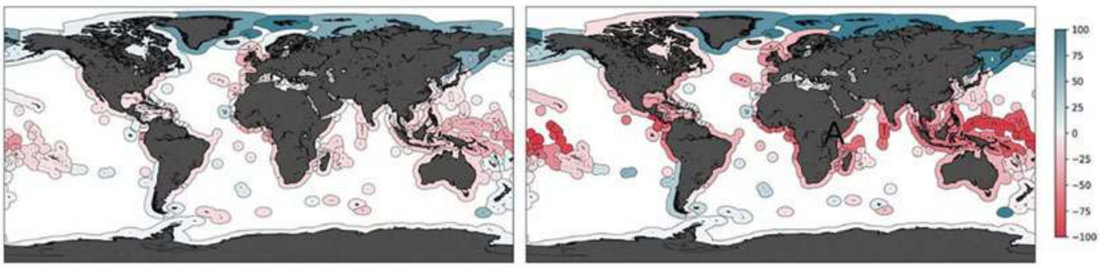


Figure I.2 – Projected changes in maximum fisheries catch potential (%) by the end of the century for selected ocean regions under low (left) and high (right) greenhouse gas emission scenarios (FAO, 2018).

Between 2000 and 2050, the global fisheries revenue could decrease by as much as 10.4% under high CO_2 emission scenarios (Lam et al. 2016). However, at country level, fish prices and cross-ocean connections through distant water fishing operations might largely modify the projected climate change impacts on fisheries' revenues, in a rather unpredictable way.

Regionally, the projected increases in fish catch in high latitudes may not translate into increases in revenues because of the increasing dominance of low value fish, and the decrease in catches by vessels operating in more severely impacted distant waters. Lam et al. (2016) also showed that developing countries with high fisheries dependency will be negatively impacted.

The role of small-scale fisheries

Small-scale fisheries likely land nearly half the world's seafood

Small-scale fisheries are by no means "small" and appear to have an outsized impact on human health and nutrition, poverty alleviation, jobs, and the structure of seafood markets (Jentoft et al. 2017; Smith & Basurto 2019). In terms of employment, small-scale fisheries are by far the oceans' largest employer: greater than industrial fisheries, oil and gas, shipping, and tourism combined (World Bank 2012; OECD 2016). Small-scale fisheries likely land nearly half the world's seafood, playing a critical role in food security and nutrition, especially for those living in poverty (World Bank 2012; Bennett et al. 2018). They usually require only small capital investment, use low technology gear and vessels and often catch fish for subsistence or local markets. Small-scale fisheries are found in coastal marine areas, brackish water lagoons, and along freshwater lakes, rivers and reservoirs. Although some may be relatively well off, the majority of these people live in rural (often remote) areas, with poor standards of living, unable to influence their operating constraints (WorldFish 2018). Despite this significant contribution to food security, the position of small-scale fisheries and how they fit into the multiple activities of the rural economy remains poorly understood. Unlike large-scale industrial fisheries, they have a low visibility and receive little attention from policy-makers. They are often open access enterprises that contribute little to the national Gross Domestic Product (GDP) and command little political attention or support through research, subsidies etc. However, Small-scale fisheries are highly diverse in operation, trade markets and organization levels as our study shows. Common characteristics of our case study fisheries were: strong ties to the economy, social structure, culture and traditions of coastal towns and communities; relatively small boats (<12m); fishing activity undertaken relatively close to the coast and involving shorter periods at sea; greater direct incorporation of human labor, or the employment of more individuals per unit of caught fish; the use of techniques that are relatively selective and able to have less impact on living marine resources; closer cooperation between the fisher, the resources and the community of which he/she is part, which could facilitate understanding of the importance of properly conserving resources; and the prevalence, amongst other operators, of micro-, small and medium sized enterprises, and of family enterprises.

An European fish product consumption heavily dependent on imports from the South

As the largest seafood market and importer in the world, Europe will be particularly impacted by the effects of climate change on global fisheries. While analyzing these economic impacts on the fish products' market or on European consumption is out of the scope of the present study, a few details are provided here identifying the main importing and consuming countries and highlighting the importance of European dependency for the fish production originating from developing countries.

Trade share of fisheries and aquaculture products in Europe (extra-EU imports and exports together) reached EUR 32.28 billion in 2018, of which 82% concern imports alone. This makes the EU a world leader in fish trade, and also a net importer (EUMOFA 2019). Spain is the top-valued EU importer, mainly supplied by Morocco, Ecuador, China and Argentina (Figure I.3). More than half of Spanish imports originate from developing countries. Other large European seafood importers, such as Italy, Germany, the United Kingdom and the Netherlands, import 20-40% of total imports directly from developing countries. In the list of largest importers, Sweden is a notable exception, consuming predominantly regional fish and importing hardly any seafood from developing countries (2% share).

Seafood consumption and production in Europe are relatively stable. The largest seafood consumers live in Portugal, Spain and Malta, i.e. Southern Europe. The largest growth market is Eastern Europe where seafood products are increasingly being consumed. (EUMOFA 2019).

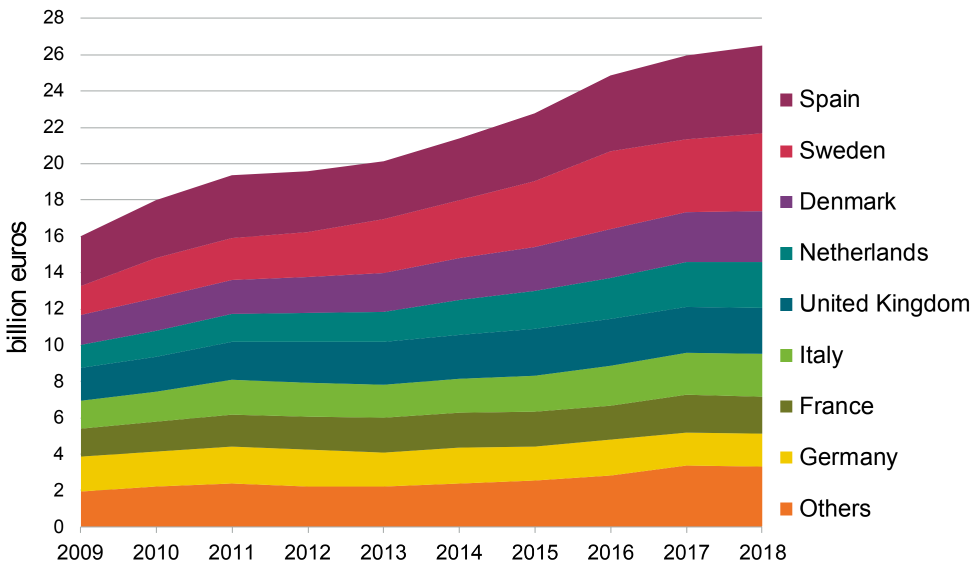


Figure I.3. Value of extra-EU imports per member state. Source: EUMOFA (2019).

Overview of main ocean-based solution options to reduce risks/impacts on fisheries

The IPCC defines adaptation as *“the process of adjustment to current or expected climate and its effects”* (IPCC 2014b).

In its synthesis of “Current knowledge, adaptation and mitigation options regarding impacts of climate change on fisheries and aquaculture” (FAO 2018), the FAO lists different adaptation tools and approaches for capture fisheries. These tools are grouped into three themes that are detailed in Table I.1:

- **Institutions**
- **Livelihoods**
- **Risk reduction and management for resilience**

These three themes will be considered in the analysis of the case studies.

A Giant trevally (Caranx ignobilis) hunting in Tubbataha Reefs, Sulu Seas, Palawan, Philippines.

Table I.1: Adaptation tools and approaches for capture fisheries as listed by the FAO (2018).

INSTITUTIONS	
Public policies	• Public investments (e.g. research, capacity building, sharing best practices and trials, communication) • Climate change adaptation policies and plans address fisheries • Provide incentives for fish products value addition and market development • Remove harmful incentives (e.g. for the expansion of fishing capacity) • Address poverty and food insecurity, which systematically limit adaptation effectiveness
Legal frameworks	• Flexible access rights to fisheries' resources in a changing climate • Dispute settlement arrangements • Adaptive legal rules • Regulatory tools (e.g. adaptive control of fishing pressure; move away from time-dependent effort control)
Institutional frameworks	• Effective arrangements for stakeholders engagement • Awareness raising and capacity building to integrate climate change into research/management/ • policy/rules • Enhanced cooperation mechanisms including those between countries to expand the capacity of fleets so that they can move between and across national boundaries in response to change in species distribution.
Management and planning	• Inclusion of climate change in management practices, e.g. EAF, including adaptive fisheries management and co-management • Inclusion of climate change in integrated coastal zone management (ICZM) • Improved water management to sustain fishery services (particularly inland) • "Adjustable" territorial use rights • Flexible seasonal rights • Temporal and spatial planning to permit stock recovery during periods when climate is favorable • Transboundary stock management to take into account changes in distribution • Enhanced resilience by reducing other non-climate stressors (e.g. habitat destruction, pollution) • Incorporation of traditional knowledge in management planning and advice for decision-making • Management/protection of critical habitats for biodiversity and recruitment

LIVELIHOODS	
Within sector	• Diversification of markets/fish products, access to high-value markets, support for diversification of citizens' demands and preferences • Improvement or change of post-harvest techniques/practices and storage • Improvement of product quality: eco-labelling, reduction of post-harvest losses, value addition • Flexibility to enable seasonal migration (e.g. following stock migration) • Diversify patterns of fishing activities with respect to the species exploited, location of fishing grounds and gear used to enable greater flexibility • Private investment in adapting fishing operations, as well as private research and development and investments in technologies e.g. to predict migration routes and availability of commercial fish stocks • Adaptation oriented microfinance
Between sectors	• Livelihood diversification (e.g. switching between rice farming, tree crop farming and fishing in response to seasonal and interannual variations in fish availability) • Exit strategies for fishers to leave fishing
RISK REDUCTION AND MANAGEMENT FOR RESILIENCE	
Risk pooling and transfer	• Risk insurance • Personal savings • Social protection and safety nets • Improve financial security
Early warning	• Extreme weather and flow forecasting • Early warning communication and response systems (e.g. food safety, approaching storms) • Monitoring climate change trends, threats and opportunities (e.g. monitoring of new and more abundant species)
Risk reduction	• Risk assessment to identify risk points • Safety at sea and vessel stability • Reinforced barriers to provide a natural first line of protection from storm surges and flooding • Climate resilient infrastructure (e.g. protecting harbours and landing sites) • Address underlying poverty and food insecurity problems
Prepared-ness and response	• Better rebuilding capacities in post-disaster recovery • Rehabilitate ecosystems • Compensation (e.g. gear replacement schemes)

1.2. Case studies

Ecuadorian small-scale fisheries (mainland and Galapagos)

The Republic of Ecuador is a country with a long tradition in marine fisheries and aquaculture. Ecuador has 4,525 km of coastline within the eastern tropical Pacific, including the Galapagos Archipelago, and is located in one of the most dynamic ocean circulation systems of the world. In 2012, Ecuador accounted for 0.53% of the total world production from fishing and aquaculture (FAO 2012).

30.2 million tons total catch for all sectors from 1950 to 2010

The total catch in Ecuador (mainland) peaked at over one million tons per year in the late ’70s and’80s, with very large catches of small pelagic fish species, notably by industrial fisheries (Figure I.4). Since then, the total catch has decreased and fluctuated over the last 15 years between 300,000 and 400,000 tons. The total catch for all sectors from 1950 to 2010 was almost 30.2 million tons, of which the small pelagic fishery, small-scale fisheries, shrimp fishery and industrial tuna fishery contributed 74%, 19%, 4%, and 2% respectively (Alava et al. 2015). Ecuador is the top exporter of tuna to the EU.

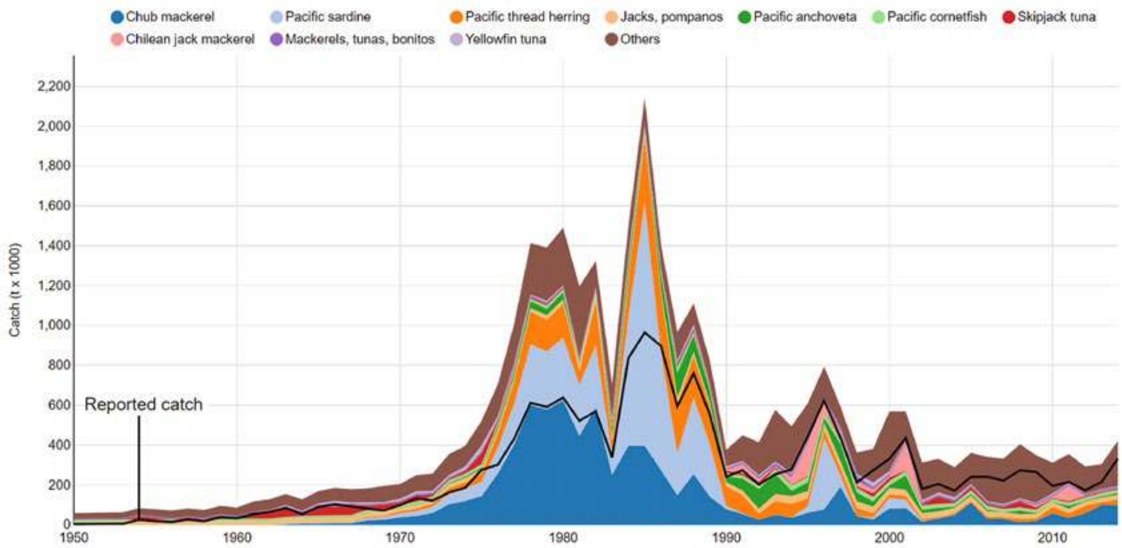


Figure I.4. Annual catch in Ecuador (mainland), from 1950 to 2014 (From Sea Around Us, seaaroundus.org; based on marine catch data from Alava et al. 2015).

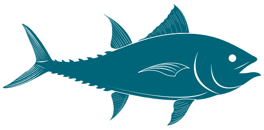
Small-scale fisheries are of primary social and economic importance in Ecuador, representing a major source of employment and food production. According to the 2013 Ecuadorian small-scale fishery census covering the five mainland coastal provinces (i.e. Esmeraldas, Manabí, Santa Elena, Guayas, and El Oro), there were 45,793 fishing boats (fibreglass and wood) operating in Ecuador, providing jobs for 57,158 fishers (Alava et al. 2015). It is estimated that the national market for fish and seafood products generated by small-scale fisheries is approximately 200 million US dollars per year.

Squids are sold at a landing site in Puerto Lopez, Ecuador

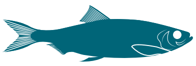
© Marion Payr / WWF

Ecuadorian small-scale fisheries are multispecies fisheries. There are two main types of small-scale fisheries. One of these is a longline fishery targeting large pelagic fish species, including dolphinfish (*Coryphaena hippurus*, also locally known as “dorado” and mahi mahi in Ecuador), tuna, billfish, and sharks. The other main small-scale fishery in Ecuador uses gillnets from individually operated skiffs. These gillnet fisheries (surface and bottom) are coastal and target a wide range of epipelagic, mid-water and demersal fishes, as well as shellfish and molluscs.

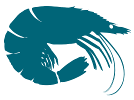
Small-scale fishing in Ecuador mainland is an ancestral activity that has developed in most of the coastal populations, concentrating much of their subsistence and food on products derived from the sea. The small-scale fishers are mostly engaged in oceanic and coastal pelagic fisheries, fishing the following species (Alava et al. 2015; Martínez-Ortiz et al. 2015).



- **Large pelagic fish** such as yellowfin tuna (*Thunnus albacares)*, bigeye tuna (*Thunnus obesus*), skipjack tuna (*Katsuwonus pelamis*), billfish, marlins (Makaira spp.), swordfish (Xiphias gladius), and “Dorado”/mahi-mahi or dolphinfish (*Coryphaena hippurus*)



- **Small pelagic fish** such as “pinchagua”/thread herrings (*Opisthonema libertate*), chub mackerel (*Scomber japonicus*), “chuhueco”/Pacific anchoveta (*Cetengraulis mysticetus*), “botellita”/bullet tuna (*Auxis rochei*). Whitefish such as “corvina”/croakers (e.g., *Cysnocion* spp.), “pargos”/snappers, “robalo”/snook (*Centropomus undecimalis*),



- **Crustaceans** (e.g. shrimp, crab), and molluscs such as cockles, mussels, clams and squid.

While the majority of small-scale fishers in Ecuador do not have an alternative productive activity to fishing, some of the additional activities that small-scale fishers and associated workers carry out, especially in closed seasons, are intended to supplement the family income. The development of this fishery is closely linked to the fishing gears and their different modalities that are used in relation to the target fisheries resource and the capture fishing zone, as well as to the influence of the currents, mainly El Niño or Panama and Humboldt or Peruvian currents, which act as modifying oceanographic factors of the ecological conditions in the marine areas adjacent to the coast. In addition, the rivers and associated basins occurring in each of the coastal provinces provide fish products, and export processes from the freshwater catches of small-scale commercial fishing affect this development (Iwaszkiw & Lacoste 2011). Fishing activity is present throughout the Ecuadorian coast. The main fishing areas are located in the Gulf of Guayaquil, Santa Elena Peninsula, Manabí Province, especially in the port of Manta, which is considered the most important tuna center in the Eastern Tropical Pacific, and El Oro and Esmeraldas provinces (Alava et al. 2015; Martínez-Ortiz et al. 2015). In addition to the marine catches off Ecuador’s main coast, fishing in continental and inland waters, including main estuaries and tributary streams or affluents formed by the Guayas, Chone, Cojimíes, Cayapas and Mataje rivers is of paramount importance (Figure I.5). In the Galapagos Islands, fishing activity, by law, is exclusively small-scale.

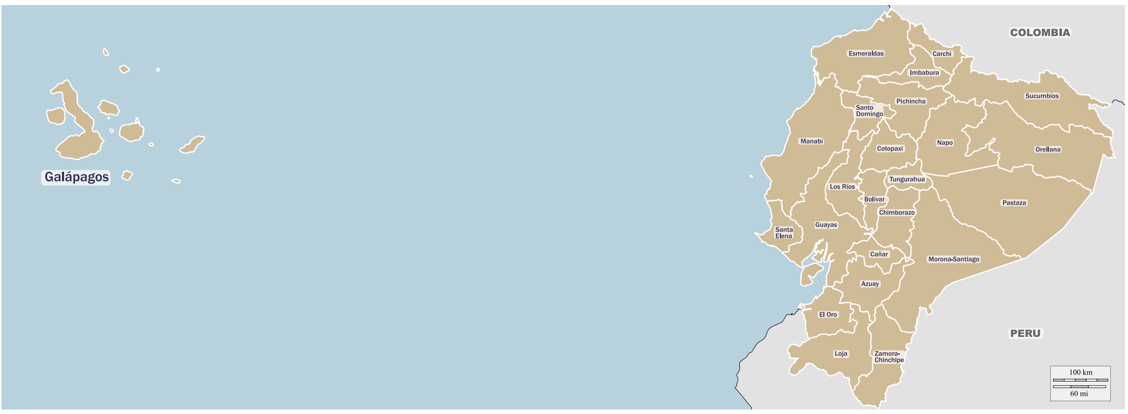


Figure I.5. Ecuador mainland and Galapagos Islands.

South African line fishery

South Africa has a coastline of some 2.798 km, extending from the Orange River in the west, on the border with Namibia, to Ponta do Ouro in the east, adjacent to Mozambique. The western coastal shelf is highly productive, in common with other upwelling ecosystems around the world, while the east coast is considerably less productive but has high species diversity, including both local and Indo-Pacific species.

The total catch in South Africa reached more than two million tons per year in the late ’60s and exceeded 1.5 million in the ’70s and late ‘80s with very large catches of small pelagics, notably by industrial fisheries (Figure I.6). Over the last years however, sardine catches drastically decreased. Hakes (shallow-water Cape hake, *Merluccius capensis* and deep-water Cape hake, *Merluccius paradoxus*) are the third most important species in terms of catch, and the first in terms of value. Hake is a very important export species and the demand from Europe for sustainable fish drove a lot of changes in the South African fisheries. Total catch decreased and fluctuated over the last 30 years between 400.000 and 1 million tons.

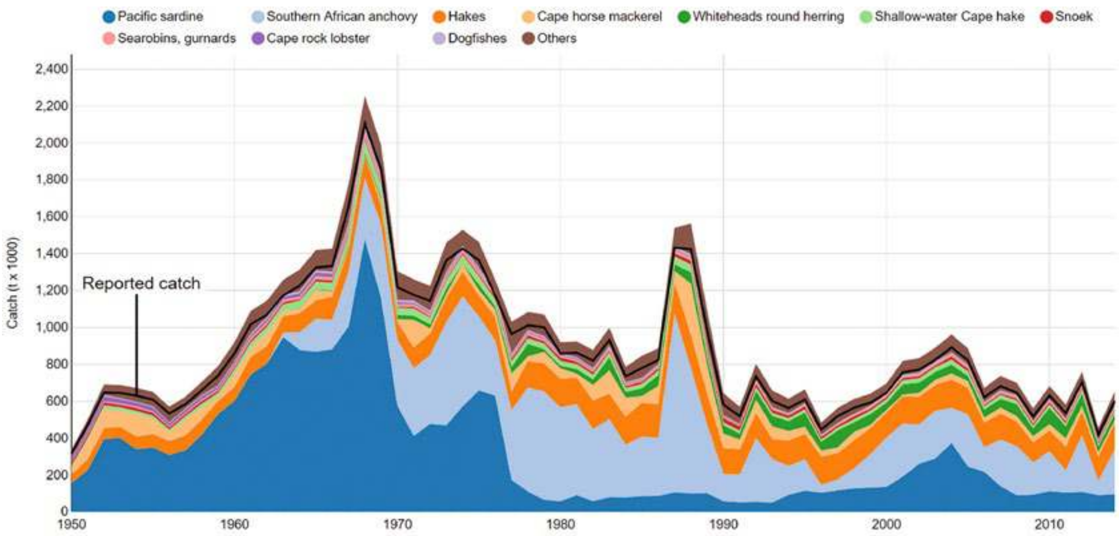


Figure I.6. Annual catch in South Africa, from 1950 to 2014 (From Sea Around Us, seaaroundus.org).

The main fishery sectors include a bottom-trawl offshore sector; a smaller bottom-trawl inshore sector; hake-directed demersal longline fisheries; tuna and swordfish-directed pelagic longline fisheries, a midwater trawl sector (for horse mackerel – *Trachurus trachurus capensis*); and a large purse-seine fishery for small pelagics, targeting pilchard (*Sardinops sagax*) and anchovy (*Engraulis capensis*), a tuna pole fishery, a linefishery, as well as a Rock lobster and a squid fishery.

A study exploring the vulnerability of South African fisheries to climate change identified the line fish and small pelagic fisheries as the most vulnerable (DAFF 2016). West Coast rock lobster, squid and marine aquaculture were identified as sectors with medium vulnerability, and fisheries employing few people and/or generating relatively little income were rated as least vulnerable because of the smaller relative consequences of change in those fisheries. Recreational fishery was given low vulnerability due to high adaptability.

This study focuses on the line fishery, as it was identified as being the most vulnerable fishery towards climate change. In South Africa, line fishing is defined as the capture of fish with hooks and lines (maximum of 10 hooks per line) but excludes the use of set pelagic or demersal long-lines. Handline fishers operate all along the South African coast (Figure I.7). Together, the three sectors of the line fishery (commercial, recreational and subsistence) target 200 of South Africa's 2200 marine fish species (WWF 2015). Most of the species caught with lines are not targeted exclusively by this fishery but are important components of the catch or the bycatch of other fisheries. This makes the management of these resources complex.

The high vulnerability of line fishery results from the fishery's sensitivity to both large and small-scale environmental changes. A large number of people are involved in line fishing and with the exception of the recreational sector, individuals and communities are generally poor, with a relatively low level of formal education, they are socially disadvantaged, resulting in a very limited capacity to adapt to adverse changes. They also have a limited agency and capacity to actively participate in the responsible management of the sector. Furthermore, they are often severely restricted by legislative and logistical constraints on the species and areas available to them, and since they operate from small boats or from the shore, they are more affected by deteriorating weather conditions than fishers in the large-scale commercial fisheries. Rapid vulnerability assessments of two communities indicated that climate change and variability, seasonal changes in fish availability, unemployment and poaching, and a lack of government support were the main stressors perceived. Changing seasons, stronger southeasterly winds in the summer and changes in West Coast rock lobster distribution were also reported (FAO 2018).

Line fisher have a limited agency and capacity to actively participate in the responsible management of the sector

The South African demersal trawl fishery was rated as one of the least vulnerable to climate change. This results from the apparent tolerance of hake to changes in the environment, and the fact that the major part of the fishery is heavily industrialized, with the financial and technical means to adapt to changes in resource abundance and distribution.

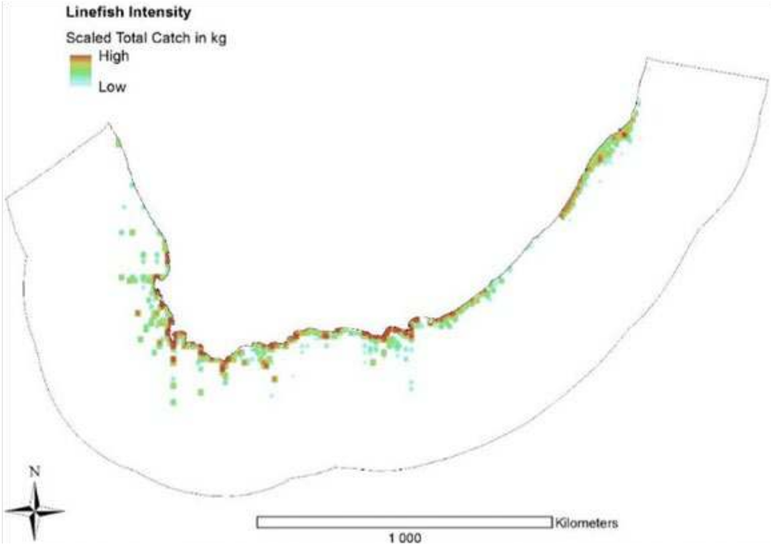


Figure I.7 – Map of intensity of commercial line fishing in South Africa from 2000-2016, displayed as scaled total catch in kilograms. Note errors in this data set, such as the record of Kosi Bay which is a reporting error. From National Biodiversity Assessment 2018: Technical Report (Volume 4: Marine).

The total number of registered vessels operating in this sector was estimated to be 700 in the late 1990s, which accounted for 37% of all boats operating in South Africa. In 2016, the total number of commercial line fishing rights available for allocation had decreased and was 455 (WWF, 2015). This fishery targets numerous species, among which eight are predominant: Snoek (*Thyrsites atun*), Carpenter seabream (*Argyrozona argyrozona*), Yellowtail amberjack (*Seriola lalandi*), Silver Kob (*Argyrosomus inodorus*), Geelbek croaker (*Atractoscion aequiden*), Hottentot seabream (*Pachymetopon blochii*), Slinger seabream (*Chrysoblephus puniceus*) and Santer (*Cheimerius nufar*). These eight species account for approximately 90% of the catch of the sector. Recently, catches from line fishery fell heavily, due mostly to a decrease in snoek catch, which is the major species by volume (Figure I.8).

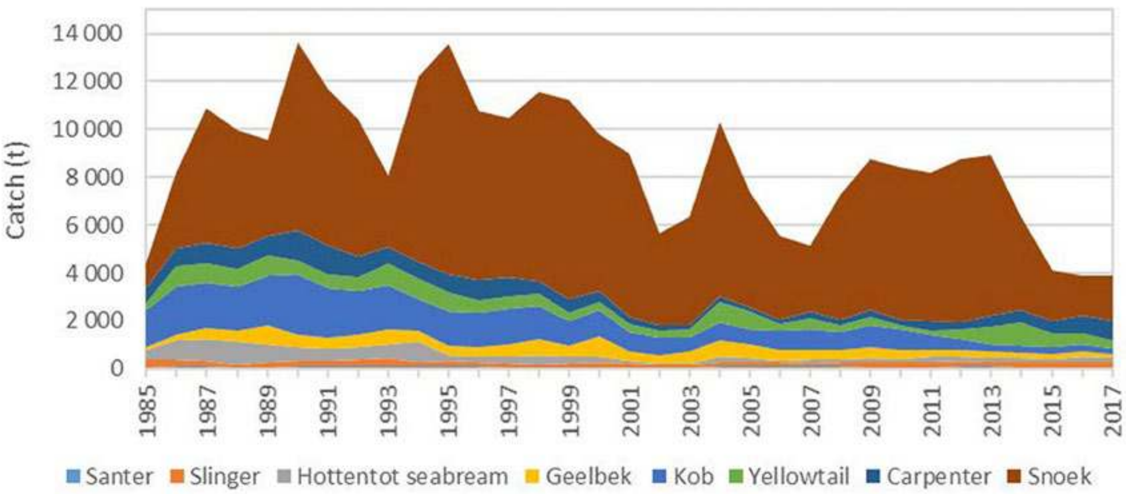


Figure I.8 – Annual catch of the main species exploited in the South African Line Fishery from 1985 to 2017 (From DAFF, Department of Agriculture, Forestry and Fisheries, 2018).

Line fishing is a low-earning, labour-intensive industry and is important from a human livelihood point of view. It employs an estimated 27% of all fishers and has the lowest average employment income of all South African fisheries. The estimated total value of the fishery is in excess of 150 million US dollars per annum (DAFF 2014), thus contributing to only 6% of the total estimated value of all South African fisheries and, despite the fact that this fishery fleet is the biggest in South Africa. The traditional line fishery is currently managed by the Department of Environment, Forestry and Fisheries (DEFF) principally through effort limitations, based on the boat and crew numbers, as well as additional restrictions such as bag limits and size limits to protect overfished species.

The results of stock assessments performed in 2017 indicate that the drastic reduction in fishing effort first in 2003 and then in 2005 (coinciding with medium term and long-term allocations) resulted in the partial recovery of some species, such as the slinger, santer, hottentot seabream and carpenter. However, other important stocks such as silver kob are still being overfished, due to the cumulative impact of the line fishery, inshore-trawl fishery and illegal gillnetting in estuaries on this species. The yellowtail assessment suggests the stock is optimally exploited, while snoek remains under-exploited. The annual catch of the nomadic yellowtail and snoek is dependent on their availability to the near-shore line fishers and is, therefore, highly variable. Moreover, the inconsistent quality of yellowtail and snoek landed by the line fishery detracts from the optimal use of these important stocks. There is also considerable inter-fishery conflict around these species which are also caught by other fisheries (e.g. trawl fishery in the case of snoek) (DAFF 2018).

Table I.2 – Summary of stock status for the main species caught by line fishers. Adapted from National Biodiversity Assessment 2018: Technical Report (Volume 4: Marine)

Stock status	Underexploited	Optimally exploited	Overexploited	Collapsed
Species	Snoek Hottentot seabream	Yellowtail Carpenter Slinger	Santer	Silver kob Geelbek

Filipino handline tuna fishery

The Philippines is a major fishing nation, with an average production of 1.9 million metric tons between 2016 and 2018. This production is equally shared between the commercial and the small-scale sector, each of them accounting for almost 1 million metric tons. The five main species caught by the commercial sector are skipjack tuna, Indian sardines, round scad, frigate tuna and yellowfin tuna. The five main species caught by the small-scale sector are Indian sardines, bigeye scad, frigate tuna, yellowfin tuna and Indian mackerel (BFAR 2019).

Tuna is the major fishery export species in the Philippines, accounting for 170,000 tons and 63.9% of fishery exports in terms of quantity and 40.7% of fishery exports in terms of value, followed by seaweeds, which account for 14% in terms of value. More than 24% of the tuna exported goes to countries belonging to the European Union (BFAR 2018). When considering all the species, the European Union gets more than 20% of the exports, second only to the USA. Major markets for tuna include Spain, Germany and the UK.

Tuna is the major fishery export species in the Philippines, accounting for 170,000 tons

The latest economic data available concerning the Philippines fisheries is for the year 2017. The project focuses on tuna fisheries in Lagonoy Gulf and Mindoro Strait, where WWF-Philippines has been working since 2011 (Figure I.9).

Lagonoy Gulf is located in the Bicol Region. It is one of the most productive fishing areas on the east coast of the Philippines, and an important spawning ground for yellowfin tuna. Fifteen municipalities surround the gulf and each of them has their own tuna fishers' association. 1,721 fishing vessels were registered in the fishery, and the landings represented 82,600 kg in 2015. The main target species is Yellowfin tuna (Thunnus albacares).Mindoro Strait is located in the MIMAROPA region. It is a corridor connecting the South China Sea with the Sulu Sea, two productive seas. It constitutes a pathway for numerous tuna species. Six municipalities are located along the west coast of Mindoro Island. 1,318 Tuna Fishing Vessels were registered in the fishery and the landings represented 54,500 kg in 2015. The main target species is also Yellowfin tuna.

Figure I.9 – Location of Mindoro Strait (West) and Lagonoy Gulf (East) in the Philippines.

Fisherman with tuna catch, Philippines

According to the latest stock assessments carried by the Western and Central Pacific Fisheries Commission (WCPFC) between 2017 and 2019 (Table I.3), these stocks are not overfished ($B>Bmsy$) and no overfishing occurs ($F<Fmsy$).

Table I.3. Stock status for three main species exploited by the Filipino hand line tuna fishery (adapted from WCPFC (2019))

Species	Overfished	Overfishing
Yellowfin tuna (*Thunnus albacares*)	No	No
Skipjack tuna (*Katsuwonus pelamis*)	No	No
Swordfish (*Xiphias gladius*)	No	No

In the Philippines, the small-scale fisheries are called "municipal fisheries". What determines the inclusion to this category is the weight of the fishing boat and the distance to shore of the fishing grounds. A municipal fishing vessel is "any watercraft used for fishing in support of fishing operations in municipal waters weighting 3 GT (gross registered tonnage) and below". The gears used in municipal fisheries are usually cast/gill nets, hook and line, spear, traps and pots, and barriers. Vessels weighing more than 3 gross tons fishing in the offshore waters belong to the commercial fishing vessels category. Municipal fishing vessels can operate in waters from 0 to 15 km from the shore, and commercial vessels usually operate beyond this zone. Commercial vessels need permission from the Local Government Units to operate within the 15 km zone, and they can only operate at a minimum distance of 10.1 km from the shore. The small-scale tuna fishery in Lagonoy Gulf and Mindoro Strait consists of handline fishing. This is a municipal fishery, with boats that are approximately 8 meters long. The handline is a selective method, which depending on the size of the hook, only mature tunas are targeted, and bycatch levels remain low. Four to five fishers work on each boat. Every fisher works with a single hook which is deployed at depths of between 50 and 150 meters. Only a few tunas are caught during each fishing trip.

2. ANALYSIS OF CLIMATE CHANGE IMPACT AND RISKS

2.1. Changes in ocean parameters

Expected changes in ocean parameters under different scenarios

The magnitude of change in ocean parameters expected from climate change in our three case studies can be anticipated based on IPCC projections of the sea surface temperature, oxygen concentration and pH (measuring water acidity). These physical parameters, which are available from Earth System Models (ESM), are key ocean ecosystem drivers that have been shown to affect species population viability (Pörtner et al. 2014).

Three Earth System Model: GFDL, IPSL and MPI

Three Earth System Model outputs were used: the Geophysical Fluid Dynamics Laboratory's ESM model (GFDL), developed in the US; the French Institute Pierre Simon Laplace's CM6-MR model (IPSL) and the German Max Planck Institute's MR model (MPI). These models provide the expected changes under various climate change scenarios in the 3 parameters, and per 0.5° x 0.5° cell surface of the global ocean.

For each parameter, an average value of the three models was calculated on an area surrounding each Exclusive Economic Zone (EEZ). The expected increase in temperature and the expected decrease in oxygen concentration and pH by the end of this century (mean value of the parameter over the 2091-2100 period) were expressed relatively to the period of reference (mean 1951 to 2000 values). The extended materials and methods can be found in the **Annex** report (Chapter 1.1).

Figure II.1 presents the projections related to the business-as-usual scenario (RCP 8.5), with the purpose to highlight the magnitude of change to be expected in each case study.

Hottentot seabreams swimming in a kelp forest, South Africa

© Philipp Kanstinger / WWF

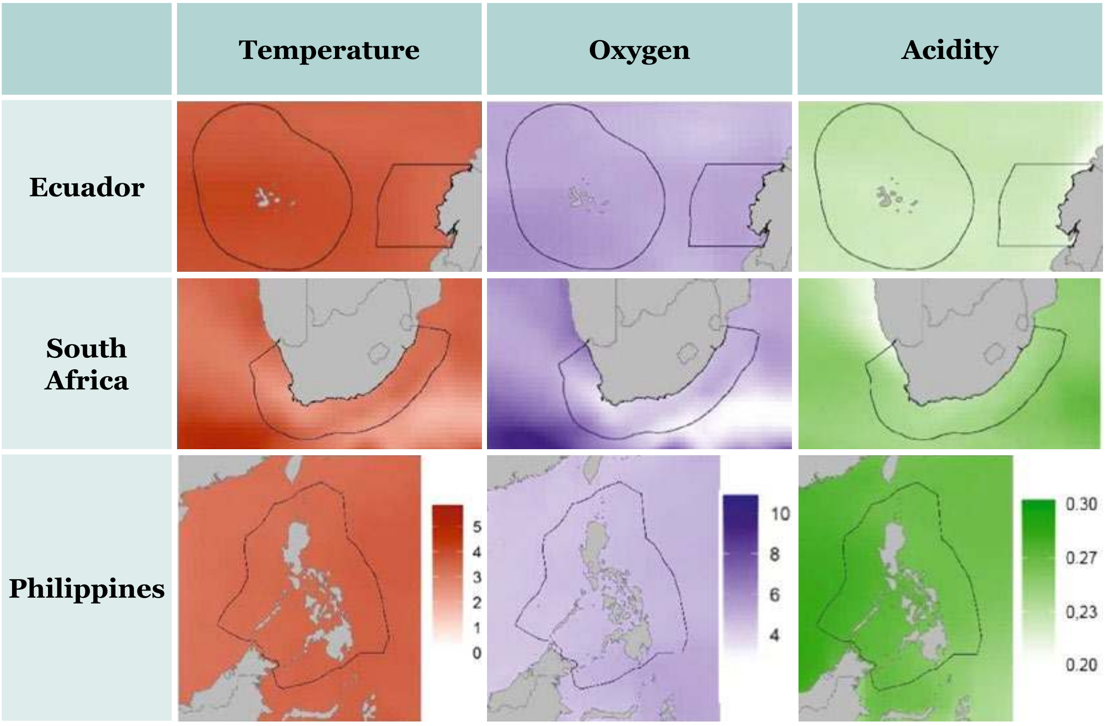


Figure II.1 – Expected change by 2100 in temperature (in °C), oxygen (concentration lost, in %) and acidity (decrease in pH), for the three case studies under the business-as-usual scenario (RCP 8.5).

The physics of the ocean is expected to change most considerably of the three case studies. In a business-as-usual scenario, and compared to the current scenario, the sea water temperature would increase by more than 2°C everywhere, while oxygen concentration would decrease by at least 2.5% and up to 10%, and pH by 0.2 to 0.25 unit by 2100.

Changes are expected to be the greatest in the Philippines. Within the EEZ, the temperature is expected to increase by between 3 and 3.7 °C, with an average of 3.4 °C, close to the expected global average (3.7 °C). Oxygen concentration and pH are also projected to decrease in the same order of magnitude as the worldwide average (-4.2% and -0.25 pH of a unit, respectively) (IPCC 2019).

Changes in South Africa should on average be less pronounced, but with a much higher variability within the EEZ. For instance, in the business-as-usual scenario, the temperature is expected to increase by between 1 and 3.5 °C depending on the area. The projected values of change in oxygen and acidity also exhibit high spatial contrasts.

In Ecuador, the average increase in temperature is expected to reach 3.5 °C in the EEZ off the Ecuadorian continental coast and 3.9 °C in and around the Galapagos Islands EEZ, with low contrasts within each area. This increase is the largest one of our case studies. In contrast, changes in pH are projected to be lower.

Silversides fish schooling among roots of red mangrove. The mangroves provide important shelter from predators for these fish.

© Tim Laman / WWF

Exposure index and intensity of the changes as compared to previous trends in the area

In order to assess in a synthetic way the magnitude of change expected in the environment in comparison to past conditions (i.e. already experienced by ecosystems), a global Exposure index (Jones & Cheung 2017) has been calculated. This index combines the measures of what is called the "climate hazard" for each parameter: temperature, oxygen and pH.

A global Exposure index combines the measures of the "climate hazard" for each parameter: temperature, oxygen and pH

For a given parameter, climate hazard is defined as the mean change in the parameter between the baseline (1951 to 2000 mean) and either 2030 (2021-2030) or 2100 (2091-2100), divided by the standard deviation over the baseline period (1951–2000). This takes into consideration the interannual environmental variability that species would be accustomed to experiencing, thereby enabling identification, across each species' distribution, of where the change in the environmental variable becomes perceptible, i.e. higher than the previously observed variability.

The Exposure index is defined using fuzzy logic methods to combine climate hazard linked to temperature, oxygen and acidity (see details on the method in the **Annex** report). It aims to take into account changes in the three parameters and their intensity relative to their variability in the period of reference. The higher the index, the higher the probability that species have never experienced that kind of variability in their environment. In other words, an index equal to 0 means that we are sure that ecosystems have already faced the projected environment, while an index equal to 100 relates to a projected environment that for sure never happened in the past 50 years.

These models show us that in all 3 case studies, and homogeneously on all the EEZs, a business-as-usual scenario implies that by 2100 (and probably before) marine species will have to live in an environment they have never encountered in the past (Figure II.2).

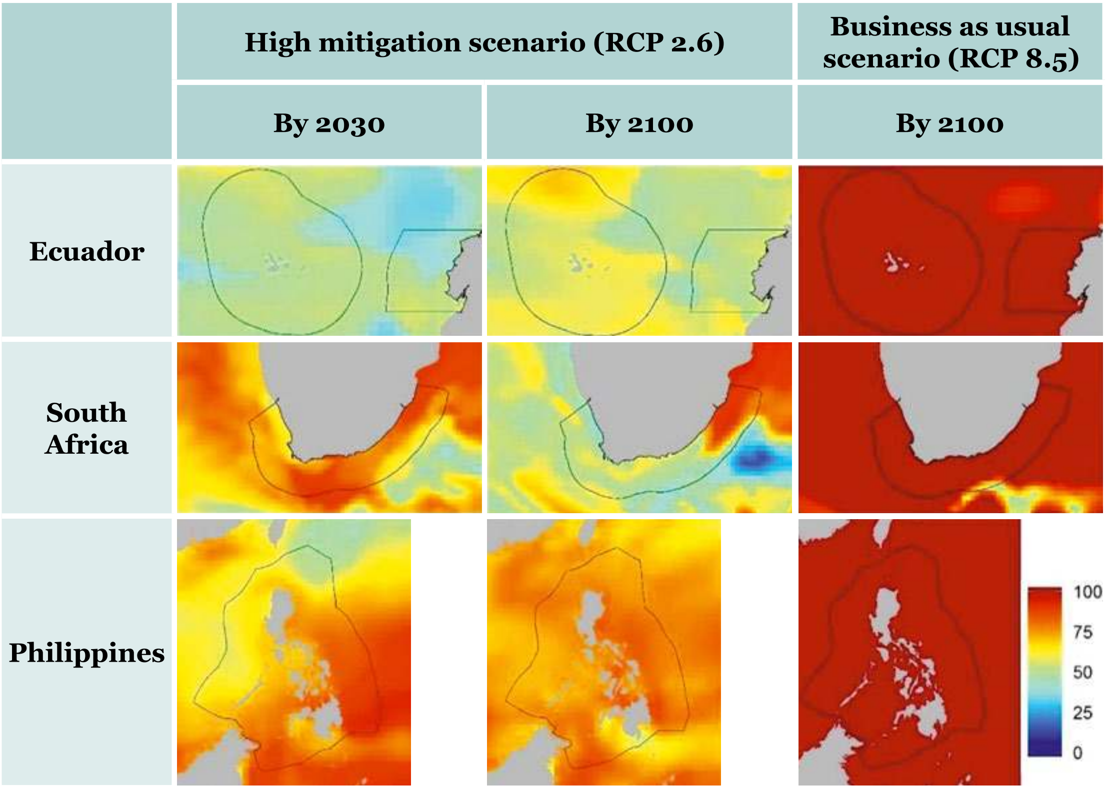


Figure II.2 – Exposure index (expressed as the probability that environmental parameters will be outside the range observed in the past 59 years) in the three case studies and for three projections of climate change (NB. projections of RCP 8.5 by 2030 would be close to those of RCP 2.6).

Under the more optimistic strong-mitigation scenario (RCP 2.6, which implies going further than the current Paris agreement), the exposure index is lower (especially in Ecuador), but by 2030 the probability of encountering unexperienced environments is still spatially reaching more than 50% within each EEZ. However, some contrasts are observed within each EEZ, suggesting that species would likely be able to find some areas of refuge. In particular, the exposure index appears lower in the Northeastern region of the Galapagos Islands EEZ, in the North part of the Ecuadorian (mainland) EEZ, on the west coast of South Africa, and in the northern part of the Filipino EEZ.

The strong-mitigation scenario would allow the exposure index to decrease between 2030 and 2100, especially in South Africa. In Ecuador and the Philippines, trends would be different, with an increasing impact in some areas and a reduction in others.

2.2. Vulnerability to climate change of the key species exploited by fisheries

With the aim to further identify which species will likely be the most affected by climate change, a Vulnerability index and changes in potential catch were estimated for a selection of species which are currently key within each case study (Table II.1). Over the last decade, these species accounted for 90%, and more than 99% of the total catch, in the line fishery of South Africa, and the tuna handline fishery of the Philippines, respectively.

Table II.1 – Species selected for their current importance in the fisheries investigated in this study.

Country	Scientific name	Common name	Production (in tons)*
Ecuador (small-scale fishery)	*Coryphaena hippurus*	Common dolphinfish	NA
	Scomber japonicus	Chub mackerel	99,400
	Opisthonema libertate	Pacific thread herring	28,820
	Mycteroperca olfax	Sailfin grouper (Galapagos bacalao)	NA
South Africa (line fishery)	*Atractoscion aequiden*	Geelbek croaker	202
	Argyrozona argyrozona	Carpenter seabream	628
	Seriola lalandi	Yellowtail amberjack	603
	Thyrsites atun	Snoek	2,378
	Argyrosomus inodorus	Silver kob	122
	Chrysoblephus puniceus	Slinger seabream	183
Philippines (tuna handline fishery)	*Makaira mazara*	Indo-Pacific blue marlin	1,359
	Acanthocybium solandri	Wahoo	2,089
	Coryphaena hippurus	Common dolphinfish	4,224
	Katsuwonus pelamis	Skipjack tuna	4,851
	Thunnus albacares	Yellowfin tuna	110,438
	Xiphias gladius	Swordfish	1,471
	Auxis thazard	Frigate tuna	105

*Ecuador: data from Sea Around us for the year 2014; South Africa: average catch between 2014 and 2017 of the line fishery sector (WWF); the Philippines: catch between august 2014 and 2015 in Mindoro strait and Lagonoy Gulf (WWF)

Species vulnerability and risk of climate impact

The vulnerability of a species, as defined by Jones & Cheung (2017), is determined by the combination of this species' sensitivity and its (lack of) adaptive capacity (Figure II.3). The sensitivity of marine fishes and invertebrates to climate change considers attributes such as temperature tolerance or maximum body length, while attributes related to the adaptive capacity are latitudinal breadth, depth range, fecundity and habitat specificity. Theoretically, vulnerability varies between 0 and 100, according to the rate conventionally associated with each attribute (see full methods in the **Annex** report).

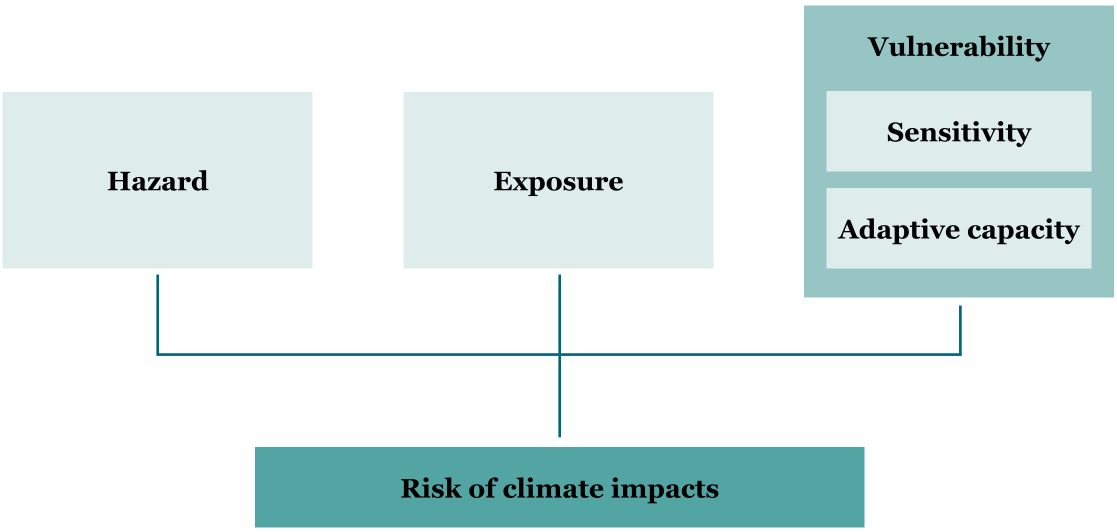


Figure II.3 Framework for assessing climate change vulnerability and risk adopted by the fifth assessment report of the IPCC (2014a)": Figure adapted from Jones & Cheung (2017).

Ultimately, the risk of impacts of climate change on a specific species is determined by three components: its vulnerability, the potential occurrence of climate-related ocean changes (i.e., the above described climate hazards related to warming, deoxygenation and ocean acidification) and the degree of exposure to such event (which depends on the species distribution).

For a given species the index of risk of climate impact is calculated within each 0.5 °x0.5° cell where the species is present (thus exposed), considering its specific vulnerability and the local Exposure index estimated under RCP 8.5 scenario in 2100. Here, a mean risk index was calculated for each of the selected species, averaging values obtained per cell at the scale of the whole EEZ area where the species is present. Therefore, the higher a species is vulnerable and distributed where the environment is expected to change greatly, the higher the risk of climate impact.

Table II.3 – Vulnerability to climate change and risk of climate impact index of the main species of the case studies. Colors define conventional classes of vulnerability and risk: low (yellow: index <50), medium (orange: 50 to 75), and high (red: >75) NA: data not available.

Country	Species	Vulnerability	Risk of climate impact
Ecuador (Small-scale fishery)	Common dolphinfish	61	77
	Chub mackerel	30	67
	Pacific thread herring	44	72
	Sailfin grouper	NA	NA
South Africa (line fishery)	Geelbek croaker	84	78
	Carpenter seabream	80	70
	Yellowtail amberjack	50	59
	Snoek	44	58
	Silver kob	NA	NA
	Slinger seabream	NA	NA
Philippines (tuna handline fishery)	Indo-Pacific blue marlin	85	87
	Wahoo	68	80
	Common dolphinfish	61	77
	Skipjack tuna	39	71
	Yellowfin tuna	39	69
	Swordfish	39	71
	Frigate tuna	29	69

Even if vulnerabilities are low for some species, the risk of climate impacts is always medium to high, due to the very high exposure index of our three case studies (at least in the RCP 8.5 scenario considered in the calculation). This means that all of the studied fisheries have to be considered at risk, with a significant part of their catch constituted by species which will likely be severely affected by climate change. This is for instance the case for the tuna hand-line fishery in the Philippines. Although tuna species have a low vulnerability index, the risk of climate impacts are high given the species' distribution also in other parts of the oceans where changes in ocean parameters are expected to be strong. This makes the risk of climate impacts quite high in those species (ranked medium).

The species composition of catch will be modified in the near future

The observed variation in species vulnerability and risk of climate change within each case study, suggest that the species composition of catch will be modified in the near future. From these particular indexes, our results show that the most affected species should be the common dolphinfish in Ecuador and the geelbek croaker in South Africa. In the Philippines, the highest impact should be seen on non-tuna species (blue marlin, wahoo and common dolphinfish).

Focus on the species' temperature range

As vulnerability indexes do not consider within each fish species the physiological limits of their temperature range (but only the size of their temperature range), a complementary analysis was conducted. Ranges of temperature preferences for each species were obtained from www.fishbase.org. By comparing the compatibility between each species range of temperature and the local expected temperature under various climate change scenarios (Figure II.4 and Table II.4), we could determine here an additional estimation of climate change impact risk.


Tuna fish landing site in Puerto Princesa, Philippines.

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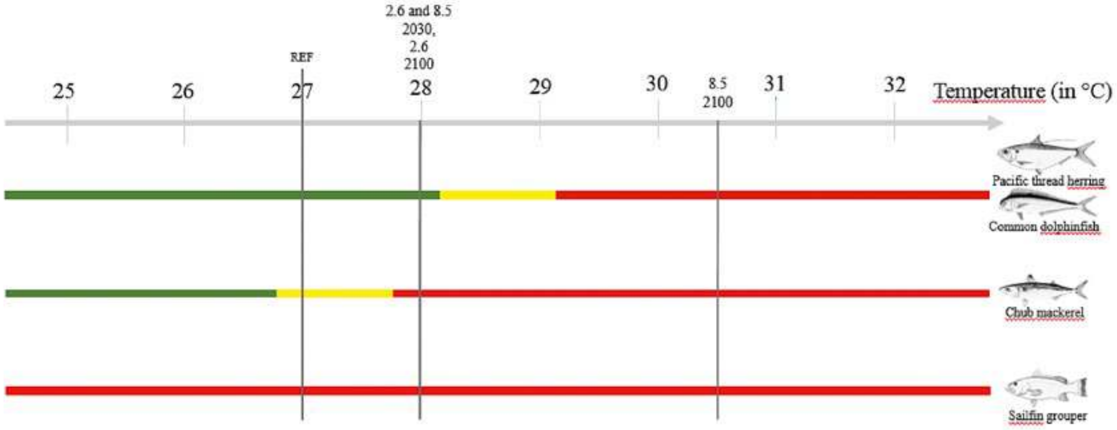
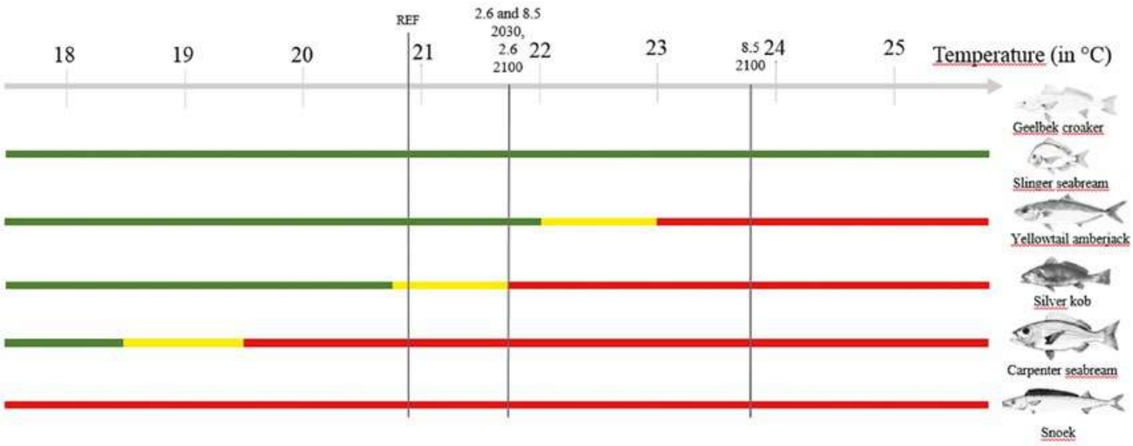
Ecuador



South Africa



Philippines

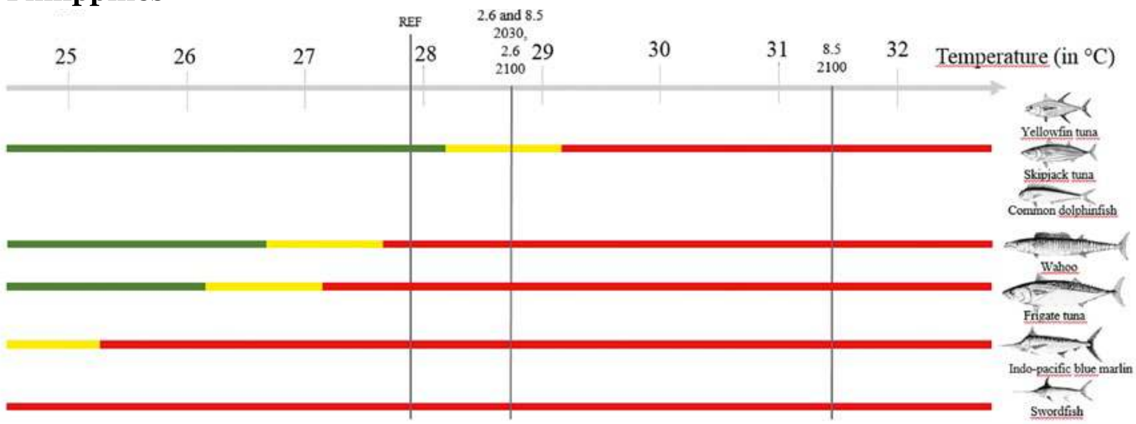
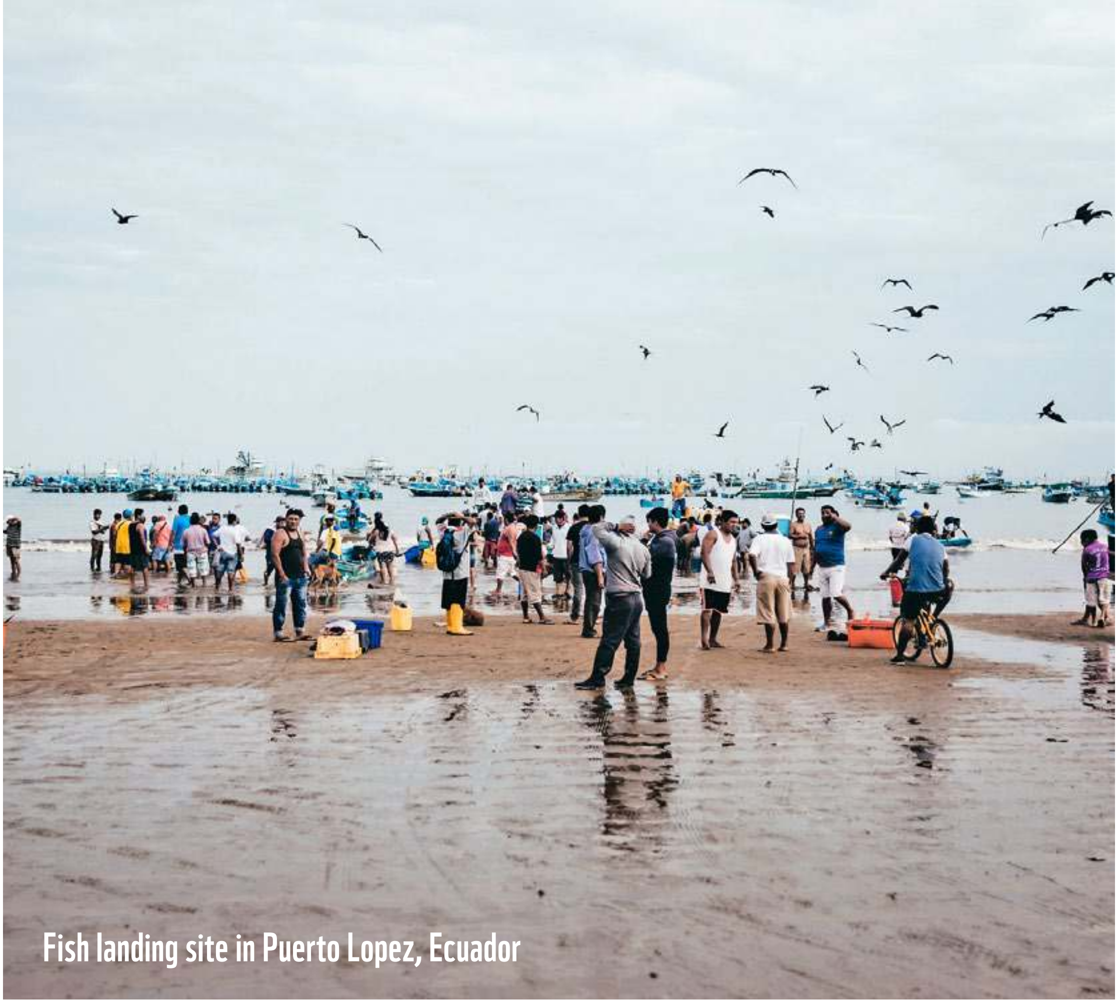


Fig II.4 – Compatibility between the expected mean sea surface temperature within the EEZ (vertical lines for the current situation and in three different climate change projections) and the species' range of temperature (in green according to FishBase; yellow range relates to a 1 °C thermic tolerance uncertainty and red range indicates temperature exceeding or well above the species preferred temperature range or maximum thermic tolerance).


Fish landing site in Puerto Lopez, Ecuador

In Ecuador, the endemic sailfin grouper from the Galapagos Islands seems to be already outside its preferred temperature range and will probably be severely impacted by sea warming, even in the case of a strong-mitigation scenario (RCP 2.6). In contrast, dolphinfish and pacific thread herring would only be impacted in case of an unfavourable business-as-usual scenario. Chub mackerel would for instance be in an intermediate situation: in the case of an optimistic scenario in which temperature would be just above their maximum preferred temperature, this species will likely be able to stay at least in some coolest parts of the EEZ.

In South Africa, snoek and carpenter seabream also appear on the edge of their temperature range and will probably be severely impacted by sea warming, even in the case of a strong-mitigation scenario. This result suggests that the rather low vulnerability index presented above for snoek is not sufficient to assess the potential impact of climate change. In other words, even if less vulnerable, snoek prefers rather cool waters and will suffer from the sea warming specifically expected within the South African EEZ. Contrary to this the geelbek croaker is classified as highly vulnerable, but is in fact a species living in hot temperatures and thus it will probably suffer less from the sea warming expected in the South African EEZ, even in the worst scenario (RCP 8.5 in 2100).

In the EEZ waters of the Philippines, most of the currently exploited species are at the higher edge of their temperature range and any warming is likely to affect them severely. This is particularly the case for swordfish and blue marlin, which should be impacted even by a moderate increase in sea water temperature (RCP 2.6). In contrast, an increase related to a strong-mitigation scenario, should permit yellowfin (by far the most important species of the fishery in terms of landing), skipjack and dolphinfish to stay in the range of their thermic preferences within the Filipino EEZ.

Table II.4 – Range of temperature (in °C) and risk of impact linked with temperature of the main species of the case studies. According to Figure II.4, this index is conventionally set to 0 when a species range includes the temperature expected in the worse scenario, i.e. RCP 8.5 in 2100. In contrast, it is set to 4 when even the best scenario, i.e. RCP 2.6, leads a temperature outside of the species' range. Intermediate values 1, 2 and 3 respectively refer to a green/yellow, green/red and yellow/red situation for RCP 2.6/RCP 8.5.

Country	Species	Range of temperature (as found in Fishbase)	Risk of impact linked with temperature
Ecuador (Small-scale fishery)	Common dolphinfish	18.1 – 29.1	2
	Chub mackerel	9.3 – 27.7	4
	Pacific thread herring	21.4 – 29	2
	Sailfin grouper (Galapagos)	14.5 – 23.7	4
South Africa (line fishery)	Slinger seabream	16.7 – 27	0
	Geelbek croaker	14 – 26.5	0
	Yellowtail amberjack	9.0 – 23	2
	Silver kob	13.9 – 21.7	3
	Carpenter seabream	12.6 – 19.5	4
	Snoek	6.2 – 16	4
Philippines (tuna handline fishery)	Indo-Pacific blue marlin	13.6 – 25.2	4
	Wahoo	18.2 – 27.6	4
	Common dolphinfish	18.1 – 29.1	3
	Skipjack tuna	13.3 – 29	3
	Yellowfin tuna	16.5 – 28.9	3
	Swordfish	10.9 – 27.6	4
	Frigate tuna	13.8-27.1	4

Small-scale fishery in the Philippines could be heavily affected by global warming

Globally, this analysis of the thermal preferences of the main exploited fish species suggests that small-scale fisheries in the Philippines could be the most affected among our three case studies. In order to stay in the range of their preferred temperatures, all species which currently constitute the bulk of the catch are considered at risk and might have to migrate beyond the Philippine EEZ. It must be noted that indexes are calculated on average over the whole EEZ. As temperatures are not homogeneous throughout the EEZ, species might be able to remain within the EEZ in some more favorable areas (in terms of temperature). However, as most species are already outside of their comfort zone, even a limited increase in temperature is likely to have an adverse effect. Moreover, a business-as-usual scenario will likely imply that the Filipino tuna handline fishery will need to change its targeted species in the coming years or decades.

In South Africa, and to a lesser extent in Ecuador, a more contrasted situation is observed with some of the main exploited species that might be less impacted. Neverteless, the species composition of the catch will likely change in the future. An additional challenge in the future besides climate change itself, will be to avoid any overexploitation especially in species already overfished (for instance the Silver kob in South Africa; and, the Sailfin grouper in the Galapagos/Ecuador) or fully exploited (Yellowfin or Slinger seabream). In particular, Silver kob might be impacted by both overfishing and climate change impact.

A healthy coral reef patch with lila staghorn corals, Fiji

© Tom Vierus / WWF

2.3. Changes expected from climate change in the biomass and catch of the main species

Projected changes in biomass

Using a trophic-level based approach developed by Du Pontavice et al. (2019), changes in the ecosystem biomass expected from various climate change scenarios were estimated within each case study. This approach also provides estimates of biomass changes per trophic level which can be considered a proxy of the expected impacts at the species level.

This approach is based on the EcoTroph model (Gascuel et al. 2009; Gascuel et al. 2011), where the functioning of the whole trophic network present in an ecosystem is equated to a flow of biomass surging up the food web from primary producers to top predators. An EcoTroph model was set up for each year and each 0.5° x 0.5° cell of the world's oceans. Outputs of the IPCC Earth Systems Models (ESMs) were integrated in the EcoTroph model. ESMs provide estimates of the expected Net Primary Productions (NPP) and Sea Surface Temperatures (SST) within each cell of the world oceans for each year and each climate change scenario. The NPP determines the quantity of biomass flow entering the trophic network at trophic level 1, while temperature determines the efficiency of biomass transfers from one trophic level to the next up to top predators. Therefore, for any scenarios and years, the model provides estimates of the amount of biomass at each trophic level (i.e. for one trophic level, it provides the sum of biomass of each species belonging to this trophic level).

Here, the three above-mentioned ESMs (GFDL, IPSL and MPI) and related averages were used to calculate changes in ecosystem biomass expected from climate change at the scale of each country EEZ related to our case studies. We used the specific change estimated for the whole trophic class each species belongs to, as a proxy of the expected impact on the abundance of our key species. Assuming no change in the fishing patterns, this approach also highlights the expected climate change impact on the catch of species belonging to the studied trophic levels. Two projected years (2030 and 2100) and two climate change scenarios were considered: the strong mitigation scenario (RCP 2.6) and the business-as-usual scenario (RCP 8.5) (Table II.3).

Table II.3 – Changes expected in the total biomass of trophic classes each species belongs to (in % of the current catch), by 2030 and 2100 and for two climate change scenarios (strong mitigation RCP 2.6 and business-as-usual RCP 8.5. Colors refer to conventional limits at -8 and -11%).

Country	**Species**	**Trophic level**	**Change in biomass (%)**			
			2030		**2100**	
			RCP 2.6	RCP 8.5	RCP 2.6	RCP8.5
Ecuador (Small-scale fishery)	Pacific thread herring	2.9 ± 0.2	-5.9	-8.1	-6.0	-11.4
	Chub mackerel	3.4 ± 0.2	-6.5	-8.9	-6.7	-12.5
	Common dolphinfish	4.4 ± 0.2	-7.6	-10.2	-7.7	-14.1
	Sailfin grouper	4.5 ± 0.2	-8.3	-10.8	-8.0	-15.6
South Africa (line fishery)	Carpenter seabream Slinger seabream	3.5 ± 0.2	-7.9	-7.9	-6.9	-8.4
	Snoek	3.6 ± 0.2	-8.3	-8.2	-7.2	-9.0
	Silver kob Yellowtail	4.2 ± 0.2	-10.4	-10.4	-9.0	-12.0
	Geelbek croaker	4.5 ± 0.2	-11.4	-11.4	-9.8	-13.3
Philippines (tuna handline fishery)	Wahoo	4.3 ± 0.2	-11.4	-12.4	-10.5	-19.1
	Yellowfin tuna Frigate tuna Skipjack tuna	4.4 ± 0.2	-11.5	-12.7	-10.5	-19.5
	Common dolphinfish Swordfish Indo-Pacific blue marlin	4.5 ± 0.2	-11.6	-12.6	-10.6	-19.3

Our results show that irrespective of the fishery type, the RCP scenario, or the projected year (2030, 2100), the biomass of the species targeted by the different fisheries assessed here are expected to decrease due to climate change. As soon as 2030, the decrease is expected to reach more than 5%, and to be much stronger in the business-as-usual scenario, with a more than 8% reduction in catch for all the assessed species. By the end of the century, the decrease might reach almost 20% for some species in the Philippines.

In each case study and for a given scenario, a general rule emerging from this approach is that the higher the trophic level of a species, the higher the expected impact of climate change. This rule, known as the trophic amplification process (Chust et al. 2014; Stock et al. 2014; Du Pontavice et al. 2019), results from the cumulative effect of the decrease in the efficiency of trophic transfers along the food web. This implies that the main predators will be particularly affected, due to the decrease in the efficient trophic functioning of the whole ecosystem.

The lowest decrease is expected in Ecuador where several species exploited by the small-scale fisheries are of low trophic level (in particular the Pacific thread herring, but also the Chub mackerel). Even in this case, biomass reductions would reach 6 to 10% by 2030 and might drop by more than 12% by 2100 in the RCP 8.5 scenario; however, it will drop by -14% for Dolphinfish/"Dorado" and -16% for the Sailfin grouper (Table II.3).

The strongest impact in terms of biomass decrease is expected for the tuna handline fishery of the Philippines. This is where changes in temperature are expected to be largest and the fishery is targeting exclusively species with a high trophic level. The loss in abundance is expected here to be around 11 or 12% for all species by 2030 irrespective of the RCP scenario, and to drop by close to 20% by the end of the century under the business-as-usual scenario.

Finally, impacts expected from a less efficient functioning of the marine food web are more varied for the targeted species of the South African line fishery. The analysis reveals that the most threatened species would be the Geelbek croaker (a high trophic level species), while Carpenter seabream (low trophic level) would be less impacted. These results are in contrast to those based on the compatibility between the increase in sea temperature and each species' temperature range. Importantly, this highlights that processes by which climate change will affect species in the future can differ from one species to another. Ultimately, this suggests that most species will likely be impacted, or at least more species than suggested by every specific analysis based on a single process approach. In other words, drawing conclusions from a single analysis (i.e. home ranges and fish distribution only, or life-traits based vulnerability only), would provide an underestimated picture of the likely effects of climate change on each fish species. In contrast, considering all variables and all processes at play will likely to tell us that most if not all the investigated species will, in one way or another, be negatively affected.

Most if not all the investigated species will, in one way or another, be negatively affected

Projected changes in total catch potential

Dynamic size-based food web models allow us to estimate the impact of climate change on the total catch potential for each of the world's EEZs (FAO 2018). These results are provided by the FAO on the scale of the whole EEZs (Table II.4), thus referring to all species and all fisheries and not specifically to our case studies. Other models called dynamic bioclimatic envelope models (DBEM) (Cheung et al. 2016) also provide similar kinds of outputs. As some values seemed inconsistent, we chose to show the outputs of the dynamic size-based food web model. However, the results of DBEM models are given in the **Annex** report.

Table II.4 – Projected changes in catch potential (%) by 2050 and 2100 in relation to 2000 under RCP 2.6 and RCP 8.5, based on outputs from the dynamic size-based food web model. The table shows the average change per EEZ as well as the variability (range) around the average and represents the different estimates from the array of climate models used to drive the fisheries projections. Adapted from FAO (2018).

Country	2050				2100			
	RCP2.6		RCP8.5		RCP2.6		RCP8.5	
	Average	Range	Average	Range	Average	Range	Average	Range
Ecuador	-2.27	13.35	-20.53	39.15	-3.65	6.01	-31.24	38.15
Galapagos Islands (Ecuador)	-4.04	6.22	-9.56	31.37	-2.91	7.46	-19.27	47.01
South Africa	-3.72	13.84	-7.20	14.34	-0.57	6.31	-15.12	28.39
Philippines	-9.25	23.15	-23.33	23.89	-5.04	16.94	-42.19	26.63

Once again, our results show that in the case of a strong mitigation scenario, negative impacts of climate change can to some extent be hampered. Compared to the business-as-usual scenario, differences are significant as early as 2050, and even more so in 2100. In all four countries, the total potential catch is less than 10% in the RCP 2.6 scenario, which is in the same order of magnitude as the decrease in biomass observed in the previous paragraph for our species of interest. In contrast, reductions projected under the RCP 8.5 scenario are much more severe for the total potential catch than for the above-mentioned biomass per species, especially for Ecuador and the Philippines. However, the variability between ESMs is very high (thus leading to a large 'range'), pointing out some uncertainty in these more general climate change models compared to our previous analyses.

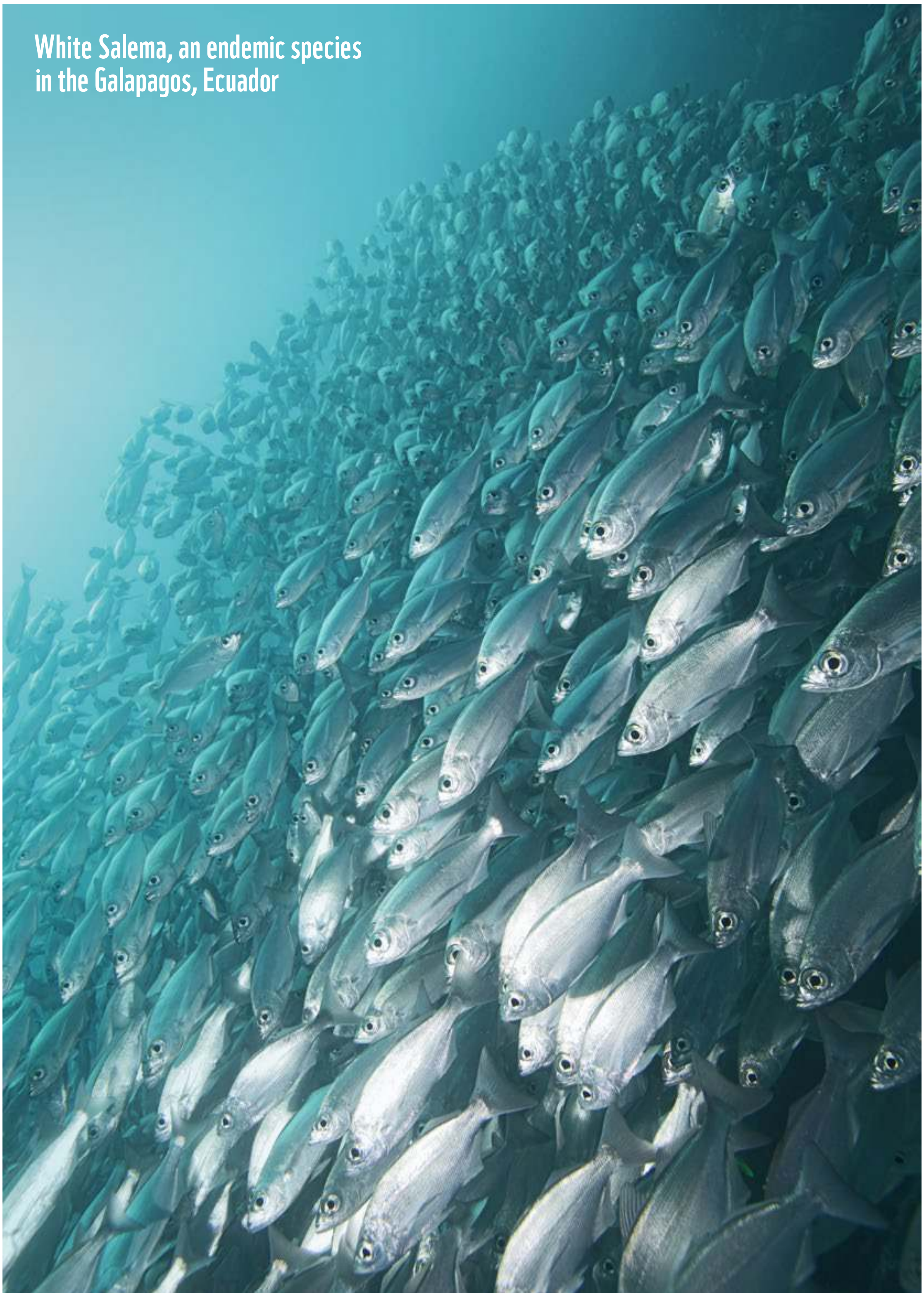
2.4. Conclusion of the modelling approach

Climate change will have a large impact on most of the fish species exploited by small-scale fishers. Even in the case of an optimistic (or favorable) strong mitigation scenario, the impact should still be significant. In our three case studies, although species show variable vulnerabilities, all have a medium or high risk of climate impact as they are located in areas where the changes in the oceanic parameters are expected to be extensive. Sea water temperatures will increase above what is considered to be the maximum preferred temperature for a large majority of the species we considered (all of them in the Philippines, even in the RCP 2.6 scenario, and almost all of them everywhere in the RCP 8.5). All species are expected to undergo a decrease in biomass levels of at least 5.9% and up to 20%.

Species will not be impacted by climate change through the same biological or ecological mechanisms (fecundity, reproduction, mortality, feeding and growth may for instance be affected differently). Thus, contrasting bio-ecological mechanisms do exist between the main species of each case study. This is especially the case in Ecuador and in South Africa, where the small-scale fisheries we studied are targeting a large diversity of fish, characterized by heterogeneous ecological life traits, including their trophic level (an important aspect in terms of sensitivity to warming). This means that different impact levels are expected from one species to the other. Consequently, species assemblages are expected to change, as well as the species composition of the catch. In other words, landings are not only projected to decrease quantitatively, but also to change qualitatively.

Among our case studies, the Philippines handline tuna fishery emerges as the most at-risk. This is especially because this fishery is mainly targeting tunas (mostly yellowfin, by far the dominant species in the catch), and more generally large pelagics, exhibiting a high trophic level and appeared particularly sensitive to climate change. For this fishery and in the absence of any improvement in fishery management or global greenhouse gas emissions, the decrease in biomass could reach almost 20% by the end of the century.

Therefore, science-based risk analyses and projections provide clear diagnoses of the likely major ecological issues that fishers already have to face and will be confronted with all the more in the coming years. Obviously, the sustainability of their fishing activities will depend on their capability to adapt fast. The next section is dedicated to the analysis of the traditional knowledge and perception stakeholders already have regarding these current and coming ecological challenges, and regarding the way fishers might adapt their activity and the management of their fisheries.



White Salema, an endemic species in the Galapagos, Ecuador

3. THE KNOWLEDGE AND PERCEPTION OF CLIMATE CHANGE BY SMALL-SCALE FISHERS AND OTHER LOCAL STAKEHOLDERS

3.1. Workshop methodology

To investigate how small-scale fishers (men and women) currently perceive the impacts of climate change on their daily fishing activities, four workshops were held (see Table III.1) in three countries. Besides fishers, these workshops were also attended by associated stakeholders from the fisheries sector in each country. Their participation helped with gathering knowledge, practices, experiences and perceptions on the social, economic and environmental impacts of climate change on local fisheries, from resource extraction to commercialization. Parts of the workshop, in some locations, also aimed at providing information to the stakeholders about climate change and its impacts on fisheries, as well as determining concrete adaptation tools.

The study of perceptions of workshop participants, qualitative, participatory, and quantitative methods were used (see the **Annex** report for the more detailed workshop methodology). We formulated and applied a set of open-ended questions in focus groups and conducted participatory interviews. Interviews allow for open-ended questions leading to nuanced understandings and rich narrative descriptions of perceptions from diverse perspectives (Bennett 2016). Gender particularities were not specifically taken into account in the workshops.

Each workshop was coordinated with the help of local organizations, as well as a local facilitator to ensure stakeholders' participation (Table III.1, see also the **Annex** report for the detailed methods of the workshops). The results of the workshops were prepared as reports to inform the current study (Rodríguez Jácome et al. 2019; Gaibor et al. 2019).

Small-scale fisherman catching fish with hook and line

Table III.1 – Workshops dates and participants. (INP: Instituto Nacional de Pesca/National Fisheries Institute of Ecuador, CDF: Charles Darwin Foundation for the Galapagos Islands).

Location	Date	Collaboration for the organisation	Facilitator	Number of participants		
				Fishers	Scientists	Decision makers
Guayaquil, Ecuador	11-12.03.19	National Fisheries Institute-INP (Nikita Gaibor), Charles Darwin Foundation-CDF (Maria José Barragan)	INP, CDF	10	18	4
Puerto Ayora, Ecuador	01.04.19		Sergio Larrea	13	2	1
Cape Town, South Africa	02-03.10.19	WWF South Africa (Monica Stassen)	Lynne Shannon	4	6	1
Legazpi, Philippines	09-10.10.19	WWF Philippines (Raisa Pandan, Joann Binondo)	Anabele Barillo	21	2	1

The workshop in South Africa gathered only few fishers, due to weather conditions being very favorable for fishing that day. However, a fair number of local scientists allowed us to gather interesting input on local fisheries and the observed effects of climate change, and to go deep in conversations with fishers.

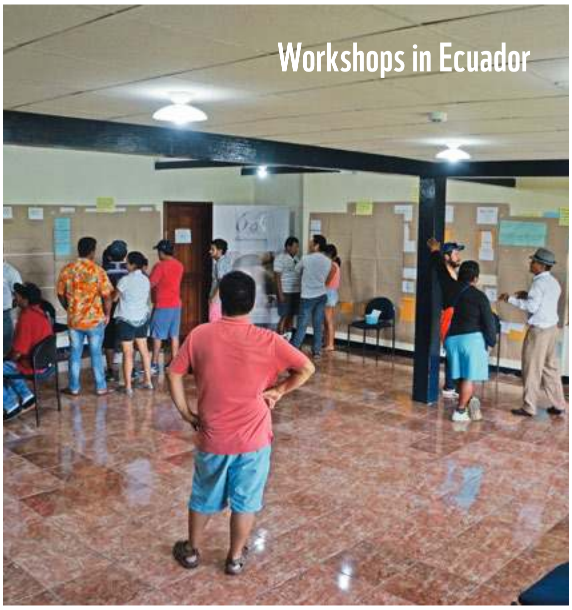
The workshops were devided in two parts (except in the Galapagos):

- PART 1 focused on climate-induced changes observed by the stakeholders (i.e. the workshop participants) regarding fishing, livelihood and quality of life.
- PART 2 concentrated on ways to adapt to climate change and to achieve / maintain a sustainable seafood production.

3.2. Main workshop outcomes

Ecuador (mainland coast + Galapagos)

Small-scale fisheries governance has evolved differently in the Ecuador mainland coast and the Galapagos Islands. Prior to March 1998, when the Galapagos Marine Reserve was created, fishing resources were nationally managed by a hierarchical centralized structure, ruled by one ministry. After the creation of the Reserve, the small-scale fisheries in the mainland remained under a hierarchical governing system but not so the fisheries of the Galapagos Islands. The islands have from that date been ruled under a Special Law for Galapagos (i.e., Ley Orgánica de Régimen Especial para la Conservación y Uso Sustentable para la Provincia de Galápagos, or LOREG). Unlike the hierarchical governance of the mainland, there was a co-governance system in place in the Galapagos Islands until 2016. Currently, the fisheries of Galapagos are ruled and governed under the Galapagos National Park Service, whereas fisheries in Ecuador's mainland coast are ruled by the Ministry of Production, Foreign Trade, Innovation and Fisheries.



Workshops in Ecuador

In both areas, the workshops conducted revealed that fishers possess vast and detailed local ecological knowledge (LEK). The small-scale fishers of Galapagos identified several mechanisms for adaptation to climate change and mitigation (details provided below). They also identified key actors and key actions to carry these mechanisms out. In addition, they proposed adaptation strategies to ensure the sustainability of seafood products and food sovereignty. Based on the fishers' perceptions, key commercial species to consider in small-scale fisheries for climate change adaptation are small-pelagic fish, dolphin fish/"dorado" (*C. hippurus*), mangrove red crab (*Ucides occidentalis*) and cockles (*Anadara* spp.), as well as the Galapagos sailfin grouper (*M. olfax*), among others.

To increase knowledge about climate change, fishers defined and prioritized topics on which they need to be trained, through capacity building. In addition, they call on institutions that support research on climate change to **inform and permanently train the sector to strengthen its capacities and build resilience**.

As proposed from the workshops, emphasis should be placed on the creation of an inter-institutional committee on climate change. It should define roles, clear responsibilities and mechanisms for inter-institutional collaboration. The workshop on the Galapagos Islands also proposed an agreement on a plan for small-scale fisheries to adapt to climate change, with emphasis on sustainability and food sovereignty in the Galapagos. Additionally, a disaster risk management toolkit, being to date only poorly addressed, was considered a key mechanism for adaptation to climate change.

The findings of the workshop underlined the importance of recognizing fishers' knowledge as valuable and complementary to scientific knowledge. From these findings, it is important to deepen the analysis and collect comprehensive information to be integrated into measures of management and administration of fisheries' resources.

South Africa

The workshop in Cape Town allowed gathering inputs from fishers and local scientists. The fishers taking part in the workshop in South Africa highlighted already observed changes as a consequence of climate change, the main ones being: 1) the abundance of snoek (the fishery's main species) decreased as the species moved deeper or further offshore, while small-scale fishers do not have boats to go fishing that far, 2) although fishers seem already to adapt to this problem, changes in seasonality is an increasing issue as they induce modifications in the areas in which fishers find the fish at a certain time of the year, and 3) other external factors, like interactions with industrial fisheries or restrictions implied by Marine Protected Areas (MPAs) currently seem to have a large impact on the line fisher's activity.

To adapt, fishers insisted on three top adaptation measures. The first one relies on the **enforcement of effective monitoring, control and surveillance**. To this end and according to fishers' suggestions, the control agency should be reinforced and tools, dedicated to the harbour's surveillance and to the reporting and control of catch statistics, should be developed. The expertise of inspectors on sustainable fishing and effective surveillance should be enhanced, as well as the information and education given to fishers regarding the importance of compliance to regulations.

Workshop in Kolk Bay, South Africa

The second main adaptation measure concerns the changes that should be made in the fisheries governance, notably by setting up or **developing more participative structures**, such as management committees, organised at fishery and regional levels, and involving all stakeholders, in consultation processes as well as in decision-making. Finally, the need for the **development of research on fisheries adaptation** to climate change was highlighted, with emphasis on the usefulness of setting up various quasi realistic scenarios of fisheries' changes, integrating the whole range of climate change scenarios and information from all stakeholders.

Fishers had the wish to be able to avoid the implication of middlemen and to have more control over fish processing and selling

Another way of adapting that seemed easily feasible was to improve the quality of fish products, and thus their value, by introducing ice on boats and facilities for fish conservation and/or processing on landing platforms. Related to this, fishers expressed the wish to be able to avoid the implication of middlemen and to have more control over fish processing and selling. As there were no fisherwomen in the South African workshop, this idea came from male fishers, scientists and government officials. **Value adding activities** were not only identified as climate change adaptation but also identified as a change in commercial practices where women could play a key role.

The Philippines

The workshop held in Legazpi gathered a high number of tuna handline fishers and women involved in the sector. The stakeholders **highlighted changes in the health of ecosystems, notably with the destruction of coral reefs**, which is a source of great concern. The importance of **restoring the health of ecosystems** (mainly by planting mangroves) was seen as a powerful tool to make the ecosystem more resilient to extreme events.

Most of the stakeholders taking part in the workshop (which includes a large number of women) consider themselves to be ready to adapt to climate change, as they are used to adapting to drastic changes that are caused by extreme events to which they are very exposed. The main measures to adapt to climate change as highlighted by the stakeholders are **Information, Education and Communication** for all people, from pupils and students, to fishers. The University of Catanduanes, represented by Dr. Jimmy Masagca at the workshop, already launched a program to create awareness among fishers on sustainable ways to harvest marine resources. The workshop was also seen as an informative workshop, which fishers, including women, asked for, as they want to be aware of the expected changes. Another way of adapting that came out of the workshop was to switch to species that are shown to be more resilient to climate change, but this would require conducting further studies on this topic.

As in South Africa, fishers as well as scientists and people from the government suggested **improving the quality and thus the value of fish products**, by introducing ice on boats and platforms for fish conservation and/or processing on land. Fishers also expressed the wish to be able to avoid the implication of middlemen and to have more control over fish processing and selling. This would open the door to a larger participation of women (who are already involved in selling the fish at the landing sites) and/or fishers themselves in the commercial activities.


Workshop in Legazpi, Philippines

3.3. Changes observed by the stakeholders

Data was collected from fishers through several workshop exercises during which participants were asked to list the changes they observed during the last 10 years regarding for instance weather conditions, catch, livelihood or market prices. This allowed us to identify changes observed by the stakeholders that they attributed to climate change as well as to other drivers. Fishers listed a lot of changes, which were grouped into three main categories: climatic conditions, impacts on the ecology and biology of marine resources, and fishing practices.

Table III.2 – Changes in climatic conditions already observed locally by stakeholders and attributed to climate change in the last 10 years.

CLIMATIC CONDITIONS	Ecuador Galápagos	Ecuador mainland	South Africa	Philippines
Increase in **temperature**	✔	✔	✔	
Increase in randomness of the **climatic conditions**				✔
Ocean currents (exaggerated **high tides**)		✔		
Strength of **winds** increased		✔	✔	

Tuna boat returning from sea in Barangay Lourdes, Philippines.

The most frequently mentioned sign of climate change observed by fishers is the increase in sea water temperature. But some stakeholders also spontaneously mentioned the increase in the frequency of extreme events such as high tides or strong winds. It thus appears that climate change is already a tangible reality for most of the participants in the workshops. The effects it has on marine resources and fishing activities can also be observed.

Most frequently mentioned sign of climate change is the increase in sea water temperature

Table III.3 – Changes in marine resources already observed locally by stakeholders and attributed to climate change.

ECOLOGY AND BIOLOGY OF MARINE RESOURCES	Ecuador Galápagos	Ecuador mainland	South Africa	Philippines
Decrease in fish **abundance**	✔	✔	✔	✔
Change in the **distribution** of fish	✔		✔	✔
Changes in species assemblages and trophic relationships	✔	✔	✔	
Change in seasonality/species life cycle			✔	✔
Change in **size** of fish and invertebrates		✔		✔

Among the changes in ecology and biology of marine resources, one was mentioned in all three countries: the **decrease in fish availability, either due to a decrease in fish abundance or the change in fish distribution** (further offshore or deeper).

Stakeholders also noticed changes in trophic relationships, either regarding fish predators or seabirds (in South Africa, fishers remembered seeing fewer seabirds).

Changes in seasonality and species life cycle were noticed in the Philippines and South Africa, inducing disturbances in fishing practices, notably because species were found in different places at some time of the year, pushing fishers to travel further to catch the fish (e.g. snoek in South Africa).

Finally, a decrease in the size of fish and invertebrates caught seems to be observed by stakeholders in the Philippines and Ecuador.

Small outrigger boat with fisherman pulling up a newly caught yellowfin tuna by hook and line.

Table III.4 – Changes in fishing activities and practices already observed locally by stakeholders.

FISHING PRACTICES	Ecuador Galapagos	Ecuador mainland	South Africa	Philippines
Increase in fishing **pressure on the resource** (possible overexploitation)	✔	✔	✔	✔
Increase in **distance to the shore** for fishing		✔	✔	✔
Reduced fishing yields			✔	✔
Reduced **areas** to fish	✔		✔	
Increase in the time spent in fishing				✔
Reduced number of suitable fishing days			✔	
Increase in the number of fishers				✔

In the Philippines and South Africa, fishers listed a lot of already significant changes in their activity because of climate change, in particular decreasing catches meaning they should go fishing farther offshore.

In the Galapagos, fishers identify effects on their quality of life and wellbeing as a result of climate change. They consider that the life quality of fishermen and fisherwomen has fallen as they are currently short of fish due to climate change. They mention more accidents for underwater/diving fishing (lobster, sea cucumber) due to the increasing difficulty of finding the resource.

"Climate change has affected animals on the shore (sea urchins, marine snails/slugs, corals) and that's why there is no sea cucumber."
Fisher, Isabela Island, Ecuador

"Fish, especially yellowfin tuna, have become smaller in size and moved deeper into the seas."
Fisher, Mindoro Strait, Philippines

"The corals turned white and died."
Fisher, Mindoro Strait, Philippines

"Currently, there is no fish entering the Gulf of Guayaquil to spawn."
Fisher, Guayaquil, Ecuador

"The ocean currents around the cape changed."
Fisher, Kolk Bay, South Africa

3.4. Risk perception by the stakeholders

On the second day of each workshop, the stakeholders were asked to vote (and to justify their votes) on a scale of 1 to 10, by answering two questions:

- **How worried are you about climate change?**
  (1 meaning "I am not worried", 10 meaning "I am very worried")

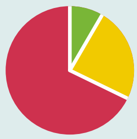
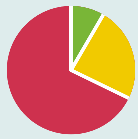
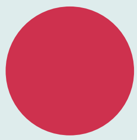
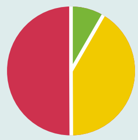
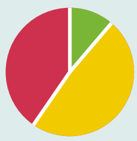
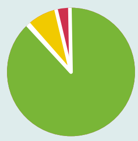
- **Do you think the fishery sector is ready to adapt to climate change?**
  (1 meaning "The sector is not ready", 10 meaning "The sector is ready")

Out of these, categories were made, regarding:

- **Concern:**
  1-3: not worried (green); 4-7: moderately worried (yellow); 8-10: very worried (red)

- **Readiness to adapt:**
  1-3: not ready to adapt (red); 4-7: moderately ready to adapt (yellow); 8-10: ready to adapt (green)

Table III.5 – Shares of the votes regarding the stakeholders' level of concern and readiness to adapt to climate change.

	Concern		**Readiness to adapt**	
Ecuador		Not worried; Moderately worried; Very worried		Ready to adapt; Moderately ready to adapt; Not ready to adapt
South Africa				
The Philippines				

In all three countries, most of the stakeholders declare themselves to be very worried about climate change, with the highest share in South Africa, where all the stakeholders declared they were worried.

There is a high variability across the different countries regarding the readiness of the sector to face climate change. The Philippines shows a high share of stakeholders declaring they are ready to face climate change, arguing that they are used to changes and to adapting to extreme events.

"We are not ready and we are worried."
Pescador (fisher) San Cristóbal Island, Ecuador

"I am not worried. We can't change fate."
Fisher, Lagonoy Gulf, Philippines Lagonoy Gulf

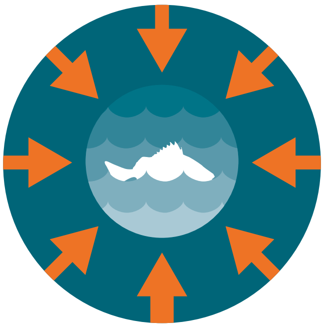
"The fishing sector is not ready, but we, the fishers, have always been good observers and will discover in time the mechanism to overcome climate change effects."
Fisher, Isabela Island, Ecuador

"I am very worried. It affects my economy and therefore the wellbeing of my family."
Fisher, Isabela Island, Ecuador

Table III.6 – Justifications the stakeholders gave when asked whether they are worried about climate change (W) or feel ready to adapt (A). The colours correspond to the categories defined earlier. Concern: green: not worried, yellow: moderately worried, red: very worried Adaptation: red: not ready to adapt, yellow: moderately ready to adapt, green: ready to adapt. Empty cells mean the justification was not given by any stakeholder of the respective case study.

	EC	SA	PH
ENVIRONMENT			
Impacts on nature (coral reefs being destroyed)	wA	w	w
Decrease in fish abundance and change in distribution, further offshore	w	w	w
Bigger and more violent waves are bound to affect the lives and livelihoods of fishers			w
Increase in temperature	A		w
LIVELIHOOD			
Affecting fishers for a long time	A	w	w
Rising costs, crash of livelihoods	w		w
Impact for the **future generations**	w		
Dependence on climatic conditions to work at sea	w		
MEANS OF ACTION			
Climate change can't be controlled	w		w
Ability to act only at time of event	w		
Lack of action from the **institutions**			w
Preparedness of the sector	A		wA
Solutions exist/do not exist	wA		w
Adaptive capacity of the fishery	A	A	
Implies a **change in fishing practices**		w	
Gap between fishers, managers and scientists		A	
KNOWLEDGE			
Lack of knowledge about climate change	Aw		w
Too few fishers informed about climate change		A	
Uncertainty around the effects of climate change			w
Empirical knowledge of the fishers and **ability to find mechanisms** to overcome changes in time	A		
Research on CC can maximize the chances of adapting			A

The reasons stakeholders felt worried (or not) about climate change, and/or thought the sector is ready to adapt to climate change, can be classified into four categories: environment, livelihood, means of actions and knowledge (Table III.6).



The **impact on the environment**, containing impacts on habitats and climatic conditions as well as impacts on availability of the fish resources, were generally seen as very worrying and gave the feeling that the fishery sector is not ready to adapt.

The **impact on livelihoods** is also seen as worrying and the stakeholders expressed that they are not ready to adapt (only bad impacts were listed).

When it comes to the **means of actions** to face climate change, the stakeholders showed opinions that are more mixed. In the Philippines,the sector felt ready to adapt and was not worried as climate change is seen as something that cannot be controlled. In contrast, Ecuadorians see this as a reason to be very worried about climate change. Stakeholders also judged the adaptive capacity of the fishery as good in Ecuador, whereas in South Africa it was deemed to be less adaptive. The gap in opinions between fishers, managers and scientists was highlighted in South Africa and seen as an obstacle to adaptation.

Lack of knowledge of the fishers and in general about climate change is seen as a reason to not feel ready to adapt and to be moderately worried about climate change. However, empirical and traditional knowledge of the fishers was highlighted in Ecuador, as a factor allowing to feel ready to adapt to climate change and its effect on marine ecosystems, by finding mechanisms to overcome changes in time.

4. WHAT SHOULD BE DONE TO FACE CLIMATE CHANGE?

4.1. Mitigation options

Mitigation options were mentioned by the fishers mainly in both the Ecuador and Galapagos workshops. They are especially concerned about fishing mitigation measures, such as:

- campaign to encourage the fishing sector and especially the industrial fisheries to reduce their global impacts on marine resources and ecosystems
- responsible use of fuel in fishing vessels
- pollution reduction from other vessels: tourism and industrial fishing
- use of biofuel

Mitigation measures beyond the fishery sector

But fishing is not the only source of carbon emissions, meaning that actions should be taken in other fields as well. Thus, mitigation measures beyond the fishery sector were also listed, such as: conservation of forests, improvement of waste management, respecting cleanliness, protection of mangroves, support of fishers' livelihoods, informing others of sustainable ways of fishing, conservation of fish products.

"We must adapt, evolve, change and create a new culture in the face of climate change because it affects productivity in the fishery and affects our own lives."
Pescador (fisher) Santa Cruz Island, Ecuador

4.2. Towards adaptation of fisheries practices in view of climate change

Two main categories of adaptation measures were explored with stakeholders during the workshop: adaptation of fisheries practices or fishing activities, and adaptation of fishery management. Regarding the first one, adaptation opportunities have been identified by stakeholders at sea or on land (Table IV.1)

Table IV.1 – Opportunities identified by stakeholders to adapt their fishing activities or practices in view of climate change.

		Appropriation by the stakeholders		
		EC	SA	PH
At sea	Target species that are more available and resilient to climate change		+	
	Move fishing effort further offshore (according to the decrease in abundance observed inshore)		+	+
	Improve equipment and technology	+	+	+
On land	Increase catch value (in order to avoid catch increase and overfishing)	+	+	+
	Diversify fishing activities and/or alternative jobs (in order to face a likely decrease in catch and fishing revenues)	+	+	+

In all three countries, fishers expressed that they had to go fishing further offshore and mentioned the need for improvement of their equipment and technology. The idea of switching to species showing a higher resilience towards climate change was highlighted, for instance, in South Africa. It was however emphasized that this would imply a revaluation of those species (e.g. chub mackerel).

In all three cases, fishers highlighted that their products were not valued as much as they should be and this should be improved, so that overfishing is more likely to be avoided and a decrease in landings could be compensated, at least partially, by higher prices. To this end, it seems that the first step would be to increase the fish quality, by providing ice on boats and at landing sites. In Philippines and South Africa a typical female activity is to set up a small business for producing or selling ice locally. A second step would be to empower the fishers in the selling of their catches, to avoid “middlemen” who reduce the income going to the fishers themselves. In small-scale fisheries, the selling of the catches is very often a female task: capacity in these communities should therefore be enhanced for better marketing (buying/selling) of the catch.

The resilience of a socio-ecological system depends on the current state of its local populations since its range of adaptation will be greater (FAO 2018). Reducing poverty and providing a population with basic living conditions guarantee an improved ability to adapt. As evidenced by the results, fishers are aware of climate change and its importance in affecting their resources. However, there is still much to be done to warrant and ensure better living conditions (i.e. health, education, sanitary conditions, and basic services) that will in turn increase their level of resilience.

"We will not be so heavily affected by climate change if we do not abuse nature."
Fisher, Lagonoy Gulf, Philippines Lagonoy Gulf

"Strategies to address climate change must first care for people first and foremost through education and by building equity. With this education, we can guarantee conservation and we can fight climate change."
Pescador (fisher), San Cristóbal Island, Ecuador

"We should concentrate on Mackerel, they getting more and more, and process it so we get better prices."
Fisher, Struisbaai, South Africa

"We gonna need bigger boats."
Fisher, Kolk Bay, South Africa

"We will not be so heavily affected by climate change if we do not abuse nature."
Fisher, Lagonoy Gulf, Philippines Lagonoy Gulf

4.3. Adapting the fisheries management to climate change

All stakeholders recognise that adapting fisheries management to climate change is a key challenge. The necessary adaptations can be organised and presented by considering six complementary dimensions of change depending on the management objective that is to be achieved. For each of them specific potential measures have been identified within each case study and are presented exhaustively in the **Annex** report. Here, the main aspects are summarised, specifying adaptation measures that were designated as primordial in the three countries (Table IV.2). It should be noticed that some of the mentioned measures are not climate change specific, but they are of particular importance in that context.

Table IV.2 – The six dimensions of change required in fisheries management to face climate change, and main measures listed by stakeholders in the three workshops.

Objective	Main adaptation measures listed by stakeholders	Appropriation by the stakeholders		
		EC	SA	PH
Efficient management	**Enforce effective monitoring, control and surveillance**	+	+	+
	Introduce Total Allowable Catch (TACs) in order to improve efficiency and effectiveness of sustainable stock management		+	
	Integrate permit allocation and management		+	
	Implement seasonal closures in order to improve stocks status and thus resilience	+	+	
	Improve the governance of Marine Protected Areas (MPAs)		+	
Adaptive management	Change from effort limits to catch limits in order to adjust exploitation rates to changing (and unstable) catch potential		+	
	Broaden the catch potential (to other fish species)	+	+	
	Consider all the effects of climate change in all scientific advice	+		
	Define together with all relevant stakeholders: management measures needed to reach targets of a sustainable fishery management	+	+	
Participative / collaborative management	**Inform and educate all relevant stakeholders (including fishers and their families) on the latest scientific evidence**	+	+	+
	Encourage the effective implication of women in all structure and organizations related to fisheries management	+		
	Change the fisheries governance structures	+	+	+
	Involve fishers in MPA's governance		+	
Science-based management	Reinforce stock assessments and other scientific advice	+	+	
	Develop Ecosystem Approach to Fisheries Management (EAFM) and change the targets of management accordingly		+	
	Develop research on fisheries adaptation to climate change	+	+	+
Precautionary management	Change the targets of fishery management to a more precautionary approach in order to improve ecosystem resilience		+	
	Increase minimum landing size limits or mesh size in order to reduce the fishing impact on fish stocks	+	+	
Social management and gender equity	**Better fishing access rights for small-scale fisheries**	+	+	+
	Improve gender equity (education, rights...)		+	

First, the importance of **optimal resource-management** implies the enforcement of effective monitoring, control and surveillance. For this purpose, control agencies and tools dedicated to effective surveillance should be reinforced (at all levels, from harbor inspections to final reporting). Additionally, inspector expertise regarding sustainable fishing and efficiency surveillance should be enhanced. Finally, fishers themselves should be informed and educated regarding the importance of compliance to the all fishing regulations.

Secondly, **adaptive management** is key in the context of climate change. It especially implies defining management measures on a yearly basis, involving all stakeholders (for instance changing from effort limits to catch limits in order to adjust exploitation rates to changing and unstable catch potential).

Thirdly, change in the fisheries governance structures, by **setting up or developing more participatory structures,** appears to be of high importance. This could be implemented through management committees organised at fishery and regional levels and involving all stakeholders. This would also include **co-creation of knowledge**, evaluating the field knowledge developed by fishers. This could be supported by a dialogue that supports permanent communication among institutions, in addition to maintaining proposals and firm actions over time. Initiatives of fishers should be supported and collaboration mechanisms

Shallow coral reef and mangroves with local West Papuan fishers, Indonesia

© Jürgen Freund / WWF

such as the inter-institutional climate change roundtable, could avoid “competition and redundancy among institutions” (example proposed by fishers on the Galapagos Islands). With reference to participation in decision-making, fishers consider that it is key to integrate the fisheries sector into decision-making.

Fourthly, importance was given to **developing research on fisheries adaptation to climate change**. To do so, quasi realistic scenario planning, that also integrates knowledge from all relevant stakeholders, should be built to develop a range of potential scenarios to better face climate change. This complex approach might however require difficult trade-offs given the need to incorporate social sciences into fishery and climate sciences. We highlight here the importance of also including the role of women in the fishing activities in such planning, even if that is often viewed as taboo.

Fifthly, and very importantly, the increase in variability and risk induced by climate change should lead to the **adoption of more precautionary management targets towards an ecosystem-based management of fisheries**. Minimising the fishing impact on marine biodiversity, habitats, food webs, etc, beyond the usual targets derived from single-species approaches (such as MSY), is required in order to improve ecosystem resilience. In particular, minimum landing sizes for example by increasing mesh sizes is known to be an efficient way to reduce the impact of fishing on fish stocks.

Finally, appreciation of and movement towards more sustainable fishing practices can be considered as a pathway to maximize the social and societal utility of fish we are able to extract sustainably from the sea (Gascuel et al. 2012). It can be efficiently implemented using differential access rights for more sustainably operating fisheries. In addition, increasing the quality and value of fish (through better processing and shorter supply chains, and by avoiding the middleman) can increase the income even if the fishing effort is reduced. Marketing can also support fishers with diversification, targeting a larger basket of species instead of a few vulnerable species. Gender equality has also been argued to be a key challenge to make fisheries management more efficient and sustainable. Gender equality is a driver for improving efficiency and sustainability in fisheries management (WWF 2019). This is evidenced in several studies, even though more research is needed to understand how women might receive a more prominent role in the small-scale fisher sector. Although this is a challenge, several benefits for both social and environmental sustainability will quickly be measurable.

4.4. Who should be involved in the adaptation process?

Stakeholders present at the workshops were also interviewed concerning the main authorities and/or structure that should be involved, in their opinion, in the leadership of fisheries management adaptation to face of climate change (Table III.9)

Table III.9 – Mains structures to be involved in the change of fisheries management according to the stakeholders present at the workshops.

	Ecuador	South Africa	Philippines
Regulations	• Galapagos: Directorate of the Galapagos National Park • Galapagos: Special Regime Council of the Galapagos Government • Ecuador's mainland coast and Galapagos: Ministry of Production, Foreign Trade, Innovation and Fisheries • Ecuador;s mainland coast and Galapagos: Decentralized Autonomous (Municipal) Governments	• DAFF • Fishers	• Municipal fishers • NGOs and associations • National government agencies • Local government agencies
Research and advice	• Galapagos: Charles Darwin Foundation for the Galapagos Islands • Ecuador's mainland coast and Galapagos: Navy/Armada Oceanographic Institute of Ecuador • Ecuador's mainland coast: National Fisheries Institute	• University • Fishers	• Scientists (University of Catanduanes) • Academe, university, schools • Local citizens
Funding of financing	• Ecuador's mainland coast and Galapagos: Ministry of Environment • Ecuador's mainland coast and Galapagos: Ministry of Tourism • Ecuador's mainland coast and Galapagos: Private companies, donors, research grant	*No specific questions asked during the workshop*	*No specific questions asked during the workshop*

Taytay fish landing with skipjack tuna, Philippines

5. DISCUSSION

How to activate adaptation measures in fisheries that will be highly impacted by climate change

In the attempt to better understand how to activate adaptation measures in fisheries that will be highly impacted by climate change, this study merged two approaches: determining fine-grained predictions from climate models, in concert and along with the concrete traditional/local knowledge of fishers (and other stakeholders) about how they perceive the impact of climate change on their daily fishing activities. Climate models help us to understand the long-term projections of climate change impacts, and when analysed at the local level, they help us to identify areas of highest concern. But these models still fail to determine precise adaptation measures. When complemented with local ecological knowledge, we argue that strong adaptation measures for small-scale fisheries could be implemented as soon as now. To our knowledge, this combined approach of LEK and climate change models is still lacking in climate change sciences and fisheries management and should be an avenue for future investigations.

5.1. Modelling output

Our fine-grained climatic models show that global heating is expected to have a significant adverse impact on most of the main fish species exploited by small-scale fishers in this study, even if global warming is limited to 2 C°. All considered fish species exhibit a medium or high risk of climate impacts and many of them are already or will be outside their maximum preferred temperature range. That will ultimately lead to a decrease in biomass by -5 to -20% depending on species and scenarios. The magnitude of change in ocean parameters expected from climate change in our three case studies was anticipated on the basis of IPCC projections of the sea surface temperature, oxygen concentration and pH (measuring water acidity). These physical parameters, which are available from Earth System Models (ESM), are key ocean ecosystem drivers that have been shown to affect species population viability (Pörtner et al. 2014). Climate hazard is indicated by the mean change in each environmental variable between baselines and takes into account the interannual environmental variability a species would be accustomed to experiencing. Adaptive capacity and species sensitivity were incorporated in our models with parameters on species' temperature tolerance ranges, maximum body size, latitudinal breadth, depth range, association with specific habitats, and fecundity.

Our findings of a general decrease in potential future catches with increasing temperatures in tropical regions are in line with numerous recent studies investigating the effect of climate change on fisheries (IPCC 2014a; Cheung et al. 2016). Global heating induced changes are profoundly altering the trophic networks of marine ecosystems with resulting impacts on fisheries worldwide, including: (i) displacement of stocks; (ii) increased mortality of species that are not very resistant to environmental changes, (iii) altered growth rates (Cheung et al. 2013a; Pauly & Cheung 2018), and (iv) impacts on behaviour of species (Clark 2006; Pankhurst & Munday 2011; Pörtner et al. 2014; Dixson et al. 2015; Nagelkerken et al. 2016; Pistevos et al. 2017).

It has to be kept in mind that our simulations were very limited for various factors and processes caused directly or indirectly by climate change such as excessive proliferation of Harmful Algal Blooms (HABs) (Lam et al. 2012), altered trophic flows and cyanobacterial proliferation (Ullah et al. 2018), invasive species expansions (Hellmann et al. 2008), ecosystem degradation such as the loss of essential fish habitats (Keller et al. 2009), marine heatwave (Frölicher & Laufkötter 2018) or oxygen depletion events (Breitburg et al. 2018). It is highly likely that climate change impacts will exceed the projected losses in catch potential calculated in our models.

Hence, it is an urgent requirement that local knowledge is incorporated into and accounted for in models, resource management improved, and adaptation strategies adopted fast, in order to secure income and wellbeing in the changing situation. Future studies should address this when evaluating the vulnerability of specific small-scale fisheries as some species might be significantly richer in essential micronutrients. These species can prevent malnutrition, especially in vulnerable groups such as children or pregnant women, and their potential loss as a resource might have a much more important impact than the loss of others for healthy coastal communities (Tacon & Metian 2013).

5.2. Workshops output

Local Ecological Knowledge (LEK)

Fishers perceive many changes in their environment and their daily activities that can already be related, at least partially, to climate change. Our study clearly confirms and illustrates that the fishers' local knowledge is a valuable source of information to guide fishery management towards more sustainability. Several studies demonstrate the importance of incorporating the local knowledge of fishers into fishery and climate sciences, including the so-called "ecological and technological knowledge" (Grant & Berkes 2007); the "fishers ecological knowledge" (FEK, Johannes et al. 2000) or/and the "local ecological knowledge" (LEK Silvano & Valbo-Jørgensen 2008).

An important differentiation should be made, though. 'Local knowledge' and 'traditional knowledge' are not synonymous, and thus, should be differentiated in the context of this research. Traditional (Ecological) Knowledge is defined as an attribute of societies with historical continuity in resource use practices (Berkes et al. 1994). The main and most important difference, then, is based on for how long the human community has been living in the place, how has people been relating to the local systems, and for how long the human communities have been using (and making sense) of the resources. The temporal dimension, as seen, plays a significant role on whether 'local' or 'traditional' knowledge is produced. This situation becomes especially true in the Galapagos, where the human permanent settlement dates for less than 190 years, the fishing communities for less than 60 years, and thus, the relationship between fishers and fish, has been extended.

LEK, for example, is considered to have the potential to improve fisheries management, as it provides new information regarding the ecology, behaviour and abundance of fish species as well as of the ecological relationships with their predators (Silvano & Valbo-Jørgensen 2008; Bender et al. 2014). Others, such as Figus (2018) demonstrate the use of local knowledge of fishers in the management of commercial fisheries and Wong (2016) the use of LEK on IUCN endangered species identification: "For species that have not been described on a scale that is relevant (or large enough) for Red Listing, local resource users and people who interact with the resource might be the only source of ecological and biological information."

This study identified several ecological and biological details that are needed to improve small-scale fisheries and to better prepare them to face climate change. LEK is also referred to by the FAO (2018) to better integrate fishery management and decision-making advice into the portfolio of climate change adaptation tools. All the LEK collected during the workshops could now be integrated when authorities start developing concrete adaptation measures. However, it must be kept in mind that Chuenpagdee et al. (2006) estimated that there are at least 12 million small-scale fishers worldwide, most of whom reside in the tropics and of those only 48 participated in our workshops. By focusing on very local situations, on very few specific small-scale fishery types and on few representatives, this study is of course very limited. Nonetheless, many of the observations, challenges and potential adaptation measures recorded in our workshops were similar to the results of other studies (Johannes et al. 2000; Bender et al. 2014).

Proposed mitigation measures

"Limiting GHG emissions is currently the only option to mitigate ocean warming, acidification, deoxygenation, sea-level rise, impacts of extreme weather events and destruction of particularly sensitive ecosystems, such as coral reefs," (COP25 – Ocean and Climate Platform Policy Recommendations for "a healthy ocean, a protected climate" 2019). Burning of fossil fuels, deforestation and degradation are the largest sources of CO_2 emissions. To reach the Paris Agreement's goal to limit global warming to below 2°C the balance between carbon emissions and carbon removals needs to happen globally around mid-century to limit global warming to 1.5°C (Olhoff and Christensen 2018). Emissions from global marine fisheries amounted to 179 million tons of CO_2 per year, representing 4% of the combined fishery, agriculture and livestock emissions and 0.6% of global emissions in 2011 (Parker et al. 2018), while small-scale fisheries catch two to tenfold more fish per ton of oil consumed than large-scale industrial fisheries. Workshop participants, mainly in the Ecuadorian workshops, discussed how to further minimize their own CO_2 footprint during fishing operations. Among others, they suggested reducing the average speed of fishing vessels, supporting as much as possible the replacement of towed fishing gears (trawls and dredges) with environmentally appropriate passive gears (nets, lines, traps), and renewing and modernising fleets to increase effectiveness (e.g. fuel-efficient

engines, bigger propellers, low friction hulls). However, in order to stay within the limits of sustainable fishing and to limit impact on the resources or ecosystems, any modernization leading to an increase in the fishing power of vessels should be carefully managed. Tradeoffs have to be studied in depth with all stakeholders, with the aim of reconciling modernization (which may also improve security, on board comfort, etc.) and economic, social and ecological sustainability of fisheries.

While the overall direct CO_2 emission of the fishing sector is rather limited, the CO_2 balance of the marine ecosystems where the fisheries operate are significant. Intact seagrass beds (Duarte & Krause-Jensen 2017), mangrove forests (Alongi 2012; Lovelock et al. 2017) and healthy fish stocks (Holmlund & Hammer 1999) are major sinks in the global CO_2 pump. The value of such intact ecosystems was emphasized in the workshops and local fishers highlighted their degradation and the need for protection. The development of innovative adaptation strategies to protect and restore coastal and ocean ecosystems should be promoted, favoring nature-based adaptation solutions, in particular the restoration of mangroves, seagrass beds, coastal marshes, kelp forests, coral reefs and other coastal ecosystems that help moderate flooding and reduce the impacts of extreme weather events and rising sea levels.

Proposed adaptation measures

The impacts of climate change on fisheries and fishers, including biophysical effects on the distribution or productivity of marine and inland water stocks and populations due to ocean acidification, damage to habitat, oceanographic changes and disturbances that affect rainfall and the availability of freshwater, can significantly vary at the local or regional levels. The displacement of a high number of species is expected, and the warming of the waters will cause certain species to move towards colder zones, which will mean the "loss of traditional fishing", with fewer catches and jobs (Cheung et al. 2010; Cheung 2018). Fisheries will also be exposed to different direct and indirect climatic impacts, such as human movements and displacements (i.e. climate change refugees) because of the effects of sea level rise on communities and coastal infrastructure, and changes in the frequency, distribution and intensity of tropical storms. In the future, freshwater ecosystems will also be especially "sensitive" to climate change and fishing may be affected by extreme events. A broad range of potential adaptation measures in both fishing practices and fisheries management were identified during the workshops.

The need of fishers (and other stakeholders) to know more about natural disasters and possible impacts was identified in the first place. Rehabilitation of marine and terrestrial ecosystems was proposed as an important adaptation mechanism. Other general adaptation measures highlighted by the participants of the workshops included i) better and more effective monitoring and control of fishing activity ii) setting up participative structures in consultation processes as well as in decision- making iii) improve the quality and thus the value of fish products and better commercialization the products iv) better information, education and communication vi) the implementation of modern technologies and the use of efficient fishing gear and equipment vii) more research on fisheries' resources viii) alternative economic incomes for fishers (both fishermen and fisherwomen). Increase in the availability and potential of modern communication and surveillance technology can greatly help to implement and improve many of the above mentioned mitigation measures such as surveillance and control of fishing activity (e.g. Automatic Identification Systems (Mazzarella et al. 2014), satellite systems, drones (Toonen & Bush 2018), data collection and bycatch monitoring (e.g. use of smartphones and apps (Jeffers et al. 2019), increased safety at sea (Chauvin et al. 2010) and enhanced information, education and organizational exchange (Qureshi 2015)).

Participative management where the community and the users i.e. fishers are also part of the decision-making system has also been shown to increase the resilience of coastal communities and improve the management of the resource. In addition, it can positively support the sense of ownership and therefore the compliance with fisheries' regulation which directly benefits the sustainable use of the resource (Gutierrez et al. 2011; Rivera et al. 2015; Ojea et al. 2016).

The need for gear type modification and bigger boats was brought up by fishers

In all three case studies, the need for gear type modification and bigger boats was brought up by fishers. For example, fishers in Ecuador proposed the use of new gear such as "the modified oceanic pelagic longline fishing system" ("el empate oceánico modificado") and emphasized deep-sea fishing. Such measures should, however, be taken with particular caution, as it could also increase the fishing pressure on stocks that are already under a high fishing pressure. However, the effects of global warming can also lead to an increase in some marine resources in some locations (e.g. squids and other cephalopod species, Doubleday et al. 2016)). In other cases, the new appearance of invasive species might lead to sudden new fishing opportunities that should be timely assessed by scientists and properly managed by fishery agencies to allow a sustainable use by local fishers. In the case of new species (including alien or invasive species) fishers and consumers might need to adapt through diversification of catches, marketing and eating habits but these fisheries should nevertheless be managed carefully (Chapman et al. 2016; Vergés et al. 2019).

The local workshops uncovered a range of long lasting local user conflicts that were seemingly independent of global warming (e.g. industrial trawler versus small-scale fishers (South Africa), conflicts between Marine Protected Areas (including tourism) and issues of access rights to local users (e.g. industrial tuna fisheries versus small-scale fisheries) (Galapagos, Ecuador), and different gear types (pelagic drift nets versus hook and line fisheries, Philippines). Climate change is adding a layer of uncertainty on top of a system that is already highly complex to manage. Our study clearly demonstrates that there is room and necessity to act right now. The proposed mitigation and adaptation measures could be used as a starting point to engage a more operational concertation with more stakeholders, with the aim to build operational action plans for the adaptation of small-scale fisheries to climate change.

Fishermen return from sea with an 80kg tuna. Such large fish are increasingly rare in Barangay Sogod, Philippines.

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However, it has to be kept in mind that climate crisis consequences will be severe, even in the 2°C global warming scenario and that the power of adaptation measures are limited. If the Paris agreement is not fulfilled in the near future, changes in ocean ecosystems in many parts of the earth will become so severe that there will be no possibilities for adaptation to safeguard food sovereignty and incomes (Sumaila et al. 2011) of small-scale fisheries.

5.3. Fusion of scientific modelling and local knowledge

The current report also highlights the usefulness of science-based approaches, which appeared able to provide key elements on the expected local impacts of climate change. The approach notably allows us to identify the main species at risk and to shed light on the potential decreases expected in future catches to some orders of magnitude, even if there is a high level of uncertainty.

Due to the short duration of the project, it was unfortunately not possible to provide stakeholders (and especially workshops participants) with all of the details of our science-based approach, and to fully compare scientific and empirical stakeholder knowledge or mutually enrich them with one another. Feedback to stakeholders and cross enrichment were not feasible in South Africa or the Philippines in the timeframe of the study but complementary workshops could be organized to share the findings with the fishers and to validate them. This should be a high priority in the next steps towards building a common science and stakeholders-based adaptation of fishing practices and fisheries management.

Further scientific approaches should then be developed and as was raised during the workshops, additional scenarios need to be explored, not only considering various trajectories for climate change, but also including diverse fishing strategies or management measures. It was emphasized that these scenarios should take into consideration as many factors as possible because the impact of climate change will result from different dimensions that can be environmental, social or economic, as well as equity and gender issues (i.e climate change impacts affect more women than men; Aguilar 2009).

5.4. Gender aspects

Workshop recordings were anonymized during transcription and gender information was not included. Therefore, gender related questions were not specifically studied in the present workshops and gender equity and perspectives in the case study regions need to be further explored in the future. Women represent half of the global workforce when considering the industry as a whole (fishing, farming, processing and related services), but do not enjoy the same rights, salaries and opportunities as their male colleagues. Despite women's crucial labour and involvement they often seem to be invisible (Monfort 2015; WWF 2019). This was somehow reflected in our workshops: while a considerable number of women are engaged in fishing and processing, only in the Ecuadorian workshops were they fairly represented (50% were women). Female workers were underrepresented in the Philippine workshop (14% were women) and absent in the South African workshop.

Although these percentages in workshop participation still seem too low, the roles of women in marine policy, governance and science are evolving, and the potential for women's voices to contribute in these areas, particularly for reaching key sustainability goals, is significant (Harper et al. 2013). Decision makers should embed gender equality in all development and conservation policies to empower women in effectively fulfilling their roles as providers and environmental managers.

Local fish market in Catanduanes, Philippines

CONCLUSION

Climate change is expected to rapidly become the main driver of change

A lot of changes clearly associated with global warming and ocean heating, were noticed by fishers and expressed during the different workshops that took place in the context of the project. Other issues such as overfishing will remain ito be important drivers int he near future, but Climate change are expected to remain to rapidly become the main driver of change, globally in the ocean, and locally for ecosystems and fisher's resources. Some changes were noted by fishers in all countries as already occurring now, including the decrease in fish abundance and the need to go fishing further offshore. This finding also confirms that stakeholder knowledge should be requested and considered in decision making for fisheries management and in definition of topics that science has to study.

More generally, fishers identified several aspects relevant for climate change adaptation management:

- The need to improve safety and possibility to go fishing with stronger boats, while taking care not to increase the pressure on stocks that are already fully or overexploited.
- The lack of knowledge on certain stocks should be studied first (lack of data and thus stock status)
- The need to get a better price, and thus to improve the quality of seafood products. This might be easy first by equipping fishers and/or landing sites with ice.
- The empowerment of fishers, with regards to market aspects and equitable supply chains,
- The empowerment of fishers in the governance process through inclusion in decision making in the fisheries management
- The first step towards sustainability is, without regard to climate, a good enforcement of the regulations on fisheries
- Climate change is adding a layer of uncertainty on top of a system that is already complex to manage.

The impact of climate change factors contributes to the reduced productivity of tropical coastal ecosystems (Doney et al. 2012). Therefore, the application of innovative development approaches to small-scale fisheries is fundamental. Under that logic, Bystrom et al. (2017) suggest that the most important dimensions include the livelihoods approach (Allison & Ellis, 2001), co-management or community-based management systems (Castilla & Fernandez 1998; Castilla & Defeo 2001; Defeo & Castilla 2005), and adaptive management strategies, focused on maintaining the productive capacity and resilience of small-scale fisheries (Berkes, 2003).

The socio-ecological system includes not only the communities where small-scale fishers inhabit, but also the coastal marine environment within which they perform commercial activities (Van Putten et al. 2016). These environments, of course, are becoming vulnerable to the effects of climate change. Aligned with that notion, it has been recognised that the integration of varied disciplines is useful in dealing with these issues. Recent events and trends in international relations are making it necessary for scientists to design their projects in ways that can integrate disciplinary perspectives and learn how to communicate their results in governance processes (Bystrom et al. 2017).

Thus, the interaction between climate change, marine resources and food security emphasises the need to develop a framework for the integration of measures to adapt to climate change in fisheries for each country. Of particular concern is the need to identify susceptible and vulnerable fishing communities in order to assess the risks of the most vulnerable fishers and who are highly dependent on the nutritional value and micronutrients of fish.

The key challenge is to conciliate short- and long-term interests, times of action, challenges adaptive capacity and resilience of the socio-ecosystems.

The workshops allowed identifying a long list of potential adaptation measures, in both the fishing practices and the fisheries management. Feedback to stakeholders and cross enrichment were not feasible in South Africa and the Philippines in the timeframe of the study but complementary workshops could be organized to share with the fishers the findings and to validate them. These findings could be used as a starting point to engage an operational consultation with all stakeholders, with the aim to build operational actions plan for adaptation of small-scale fisheries to climate change.

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LIST OF ABBREVIATIONS

BFAR: Bureau of Fisheries and Aquatic Resources

CC: Climate Change

CDF: Charles Darwin Foundation

DAFF: Department of Agriculture, Forestry and Fisheries

DBEM: Dynamic Bioclimatic Envelope Models

DEFF: Department of Environment, Forestry and Fisheries

EEZ: Exclusive Economic Zone

ESM: Earth System Models

EU: European Union

EUMOFA: European Market Observatory for Fisheries and Aquaculture products

FAO: Food and Agriculture Organization

GFDL: Geophysical Fluid Dynamics Laboratory's ESM model

GHG: Greenhouse Gas

GT: Gross Registered Tonnage

IEC: Information, Education and Communication

INP: National Fisheries Institute

IPCC: Intergovernmental Panel on Climate Change

LCCAP: Local Climate Change Adaptation Plan

LEK: Local Ecological Knowledge

MPA: Marine Protected Area

MSY: Maximum Sustainable Yield

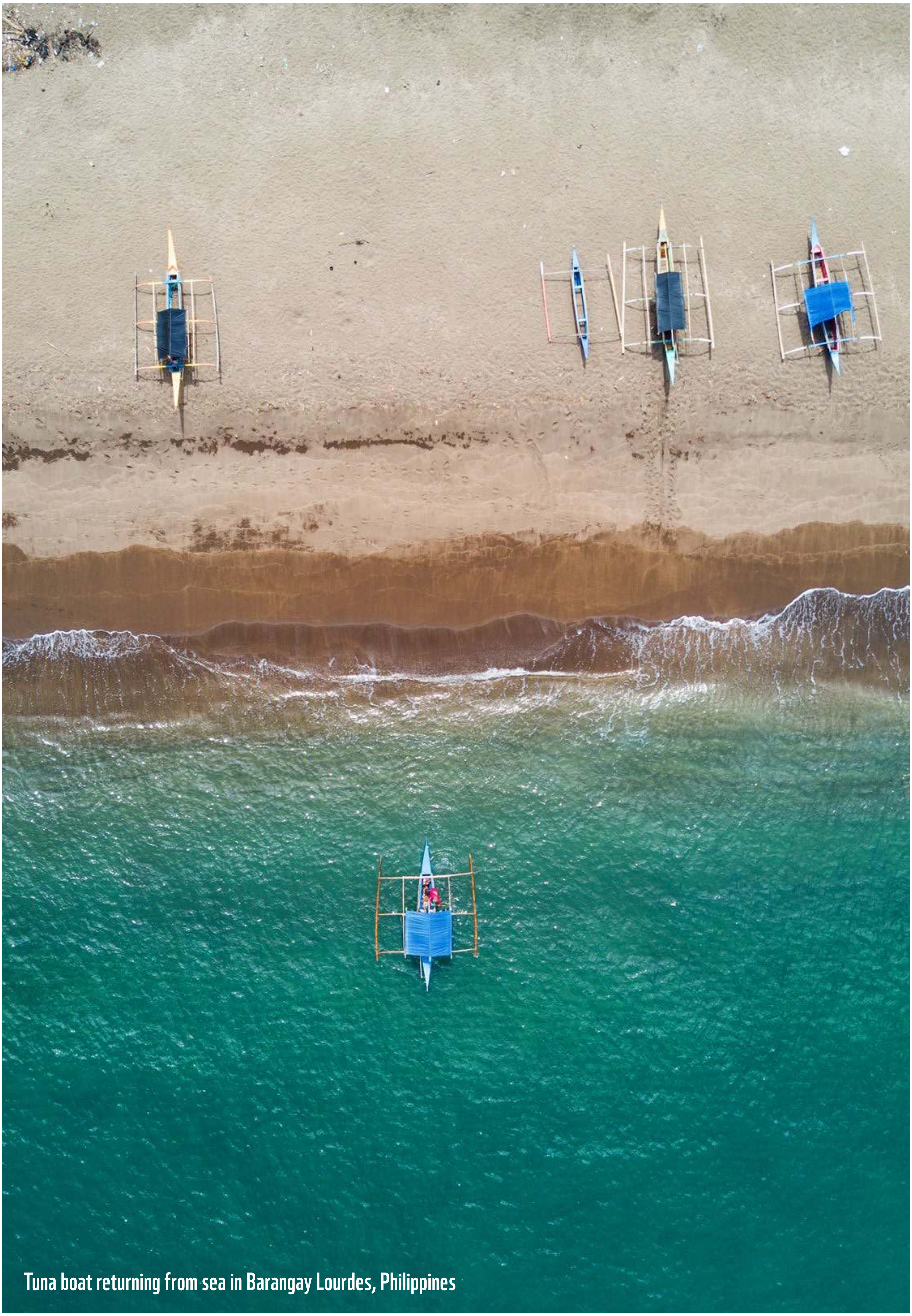
NCCAP: National Climate Change Adaptation Plan

NPP: Net Primary Productions

RCP: Representative Concentration Pathway

SST: Sea Surface Temperatures

WWF: World Wide Fund for Nature


Tuna boat returning from sea in Barangay Lourdes, Philippines

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Why we are here
To stop the degradation of the planet’s natural environment and to build a future in which humans live in harmony with nature.

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