A new climate change vulnerability assessment for fisheries and aquaculture

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Abstract

The Food and Agriculture Organization of the United Nations (FAO) has released a new global assessment of the vulnerability of fisheries and aquaculture to climate change. This major report, published as FAO Fisheries and Aquaculture Technical Paper No. 627, explains the science behind the expected effects of climate change on marine and inland capture fisheries and aquaculture worldwide, and the implications for the millions of people who depend on the fisheries sector for their livelihoods and food security. The FAO Technical Paper also presents practical approaches to adaptation to assist fisheries and aquaculture operations at all scales to reduce the risks posed by climate change, and harness opportunities. The information is set in the context of poverty alleviation, and within existing policy commitments, such as United Nations Agenda 2030 and the Paris Climate Agreement. The advice in the FAO Technical Paper on adaptations is also firmly embedded in reality – it acknowledges the interactions within the sector, the relationships between fisheries and aquaculture and with other sectors, and the influence of other important drivers such as population growth and global demand for fish. In this article, we highlight the vulnerability assessments made for industrial tuna fisheries and small-scale coastal fisheries in the western and central Pacific Ocean, the relevance of this work to Pacific Island countries and territories, and to the 'Regional roadmap for sustainable Pacific fisheries' and the 'New song for coastal fisheries – pathways to change'. We also summarise the key messages from other chapters of the FAO Technical Paper relevant to the Pacific Islands region, including the chapters on freshwater fisheries and aquaculture.

Introduction

In July 2018, the Food and Agriculture Organization of the United Nations (FAO) published Fisheries and Aquaculture Technical Paper No. 627[4], entitled 'Impacts of climate change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options' (Barange et al. 2018). This important publication synthesises the latest knowledge on the impacts of climate change on the fisheries and aquaculture sector worldwide, highlights the vulnerability of the millions of poor people who depend on the sector for their livelihoods, and describes the adaptations needed at all scales to ensure that fisheries and aquaculture continue to make important contributions to poverty alleviation and food security.

The FAO Technical Paper will be particularly useful to fisheries managers and scientists in the Pacific Islands region because it updates the information in the book published by the Pacific Community (SPC) in 2011 on 'Vulnerability of tropical Pacific fisheries and aquaculture to climate change' (Bell et al. 2011), and in the FAO report on 'Priority adaptations to climate change for Pacific fisheries and aquaculture' (Johnson et al. 2013). Chapter 14 of the FAO Technical Paper (Bell et al. 2018a) summarises the latest information available on the impacts of climate change on marine fisheries in the western and central Pacific Ocean (WCPO), the vulnerability of these resources, and practical adaptations for economies and communities.

Chapter 14 is expected to be of special interest to fisheries agencies responsible for implementing the 'Regional roadmap for sustainable Pacific fisheries' (FFA and SPC 2015) and 'A new song for coastal fisheries – pathways to change' (SPC 2015). It identifies how climate change could disrupt these plans, and the adaptations needed to minimise the risks posed by climate change and maximise the opportunities.

The adaptations to climate change recommended for inland fisheries (Chapters 18, 19 and 26) and aquaculture (Chapters 20–22) in the FAO Technical Paper also have salient lessons for the management of freshwater fisheries and marine and freshwater aquaculture in the Pacific Islands region.

In Part 1 of this article, we summarise the main findings from Chapter 14 on the regional impacts of climate change

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on marine fisheries in the WCPO. In Part 2, we draw on text from the 40-page summary of the FAO Technical Paper[5] (FAO 2018a) to outline several of the key messages for readers interested in the global perspective.

1 Climate change impacts, vulnerabilities and adaptations for WCPO marine fisheries

This latest assessment for the WCPO (Chapter 14) applies an end-to-end, climate-to-fish-to-fisheries approach to evaluate the vulnerability of the region's plans to secure and increase the socioeconomic benefits from marine fisheries for Pacific Island countries. After briefly describing the main marine fisheries of the region (Section 14.1.1), and the strategic plans and management arrangements for these fisheries (Section 14.1.2), the chapter summarises the observed and projected changes to the physical and chemical features of the WCPO, and how these changes are expected to alter fish habitats (Section 14.2).

The chapter then explains how the direct and indirect effects of continued carbon dioxide (CO_2) emissions are likely to affect the industrial tuna fisheries that underpin so many economies across the region, and the small-scale fisheries that provide coastal communities with food security and livelihoods. These analyses are based on global and regional modelling approaches incorporating the representative concentration pathways for greenhouse gas (GHG) emissions (see Part 2) used for the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), or emission scenarios from the IPCC Fourth Assessment Report (AR4).

Below, we use portions of text extracted from Chapter 14 to summarise the effects of climate change on the future production of the region's marine fisheries, the socioeconomic implications of climate-driven alterations in production, and the priority adaptations (readers interested in the full details and supporting references should read Sections 14.3 and 14.4 of the FAO Technical Paper). This information is presented firstly for industrial tuna fisheries (Section 14.3), and then for small-scale, coastal fisheries (Section 14.4).

1.1 Effects of climate change on industrial tuna fisheries

Observed and projected effects on distribution and abundance of tuna

The modelling of how tuna in the WCPO are likely to respond to long-term climate change (Fig. 1) indicates that there will be an eastward and poleward shift in tuna distribution, and reductions in total biomass, for both skipjack and yellowfin tuna under the RCP8.5 emissions scenario. These responses are driven mainly by changes in larval survival and spawning location. Decreases in the biomass of these two species will occur in most of the exclusive economic zones (EEZs) of Pacific Island countries west of 170°E, and will increase in EEZs east of 170°E. Projected percentage decreases by 2050 and 2100 relative to 2005 are particularly marked for Papua New Guinea (PNG), the Federated States of Micronesia, Nauru and Palau. However, for PNG, it is important to note that the modelling does not yet take account of possible beneficial effects of increased nutrients of terrestrial origin from higher rainfall. Substantial percentage increases in biomass relative to 2005 are projected for skipjack tuna in Vanuatu, New Caledonia, Pitcairn Islands and French Polynesia, and for yellowfin tuna in French Polynesia.

The projections for bigeye tuna and South Pacific albacore are somewhat different. For bigeye tuna, decreases in biomass are expected to occur in all EEZs (Fig. 1). For South Pacific albacore, the distributions of larvae and juveniles are expected to shift south towards the Tasman Sea after 2050. Densities of early life stages are projected to decrease in their core area (Coral Sea) by 2050, resulting in a stabilised adult biomass approximately 30 percent lower than in 2000. However, the north Tasman Sea could emerge as a new spawning ground after 2080 (Fig. 1), reversing the downward trend in abundance.

Implications for economic development

The redistribution of skipjack and yellowfin tuna is expected to result in lower catches across the prime fishing grounds by 2050, with knock-on effects on licence revenues. The plans to increase employment based on industrial fishing and processing in PNG and Solomon Islands could also be affected. This employment risk is tempered, however, by the fact that recent average tuna catches in the EEZs and archipelagic waters of PNG and Solomon Islands well exceed the capacity of existing and proposed fish-processing facilities. Nevertheless, changes in licensing conditions may be needed to ensure that more of the fish caught within the EEZs of these countries is delivered to national canneries (see below). Other possible negative impacts on economic development may occur from the eastward redistribution of bigeye tuna and the poleward movement of South Pacific albacore. In both cases, a greater proportion of longline fishing is eventually expected to occur outside the EEZs, reducing governments' revenue from licence fees. The projected eastward redistribution of skipjack and yellowfin tuna as a result of climate change could result in opportunities for Pacific Island countries and territories in the eastern WCPO (e.g. French Polynesia, and in the subtropical countries of Vanuatu and Fiji), to obtain increased economic benefits. However, although modelling indicates that the percentage increases in catch could be substantial in these EEZs, the scale of benefits is likely to be modest because present-day catches are low.

[5] http://www.fao.org/3/CA0356EN/ca0356en.pdf

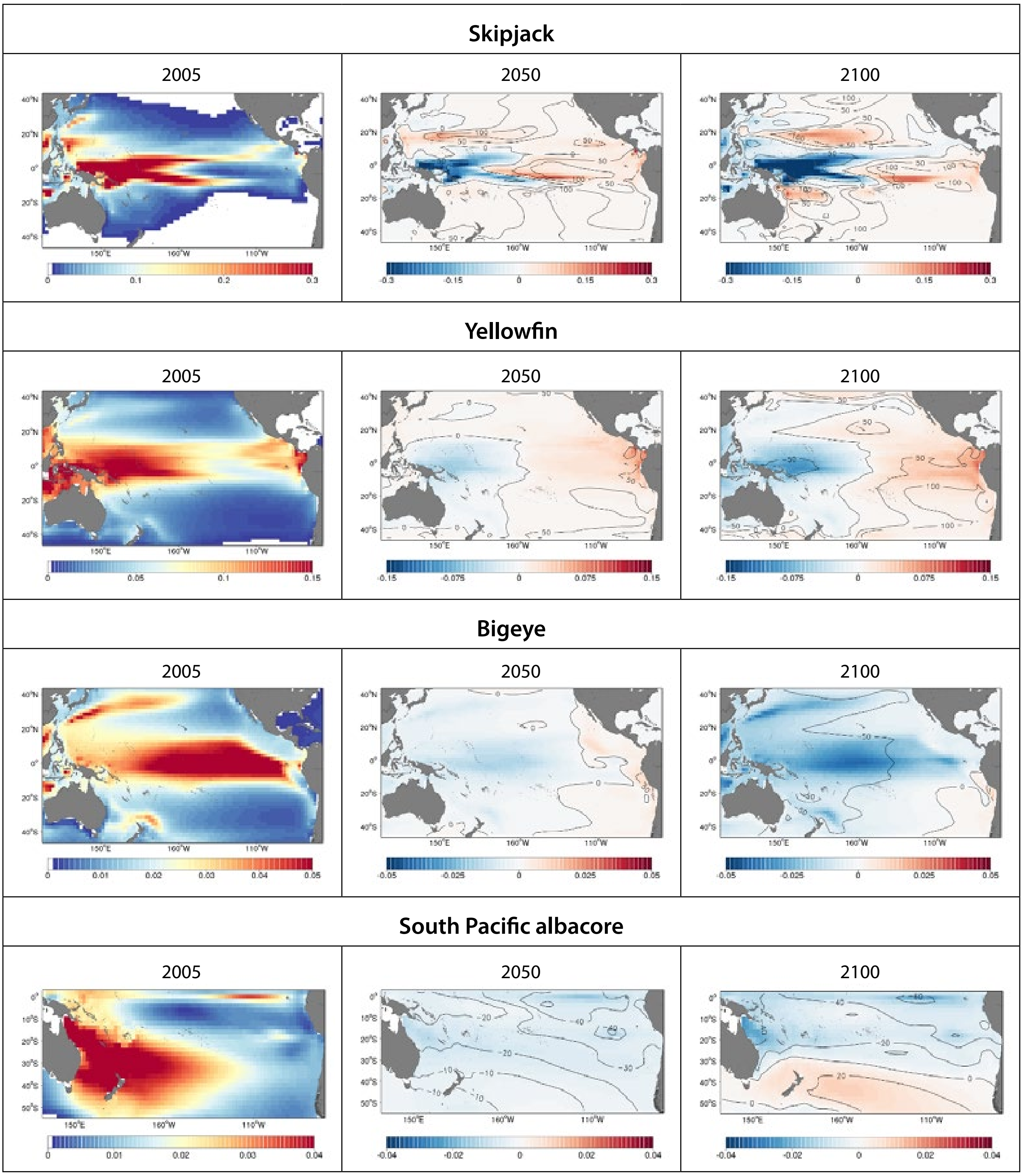


Figure 1. Average historical (2005) distributions of skipjack, yellowfin and bigeye tuna and South Pacific albacore (in tonnes per square kilometre) in the tropical Pacific Ocean, and projected changes in biomass of each species relative to 2005 under the RCP8.5 emission scenario for 2050 and 2100, simulated using SEAPODYM. Isopleths in the projections for 2050 and 2100 represent the relative percentage change in biomass caused by climate change. Source: based on modelling done for Chapter 14 of FAO Fisheries and Aquaculture Technical Paper 627 by Patrick Lehodey and Inna Senina.

Consequences for fisheries management

The modelling described above also indicates that an increase in fishing effort will exacerbate the overall decreases in the production of tuna species projected to occur as a result of climate change. To minimise the possible negative effects on tuna catches, fishing effort will need to be constrained and future harvest strategies adjusted to account for alterations in the distribution and abundance of tuna species. Other possible consequences include: 1) the need to transfer more management responsibility to the Western and Central Pacific Fisheries Commission (WCPFC) as a greater proportion of the catch is made in high seas areas; and 2) the eventual consideration of Pan-Pacific tuna management through a merger of WCPFC and the Inter-American Tropical Tuna Commission. The existing monitoring, control and surveillance of tuna catches by the Pacific Islands Forum Fisheries Agency (FFA), the Parties to the Nauru Agreement (PNA)[6] and WCPFC should help identify if and when such changes in management would be appropriate. Because eastward redistribution of tuna can be expected to increase the use of drifting fish aggregating devices (FADs) by purse-seine vessels, management will also need to ensure that the effects of FAD fishing on associated species (e.g. sharks) and juvenile bigeye tuna are mitigated effectively.

Vulnerability of tuna species, fisheries and economies

The four species of tropical tuna – albacore, bigeye, skipjack and yellowfin – are expected to have relatively low vulnerability to the projected physical and chemical changes to the WCPO, and to alterations in oceanic food webs, because they can move to areas with their preferred conditions. However, increased stratification of the water column due to increases in sea surface temperature (SST) could make the surface-dwelling skipjack and yellowfin tuna more vulnerable to capture. This assessment is based on higher catch rates for yellowfin tuna in the Western Pacific Warm Pool during El Niño events, when shoaling of the thermocline contracts the vertical habitat for this species. Increased vulnerability to capture by purse-seine fishing, and projected decreases in availability of these two species across much of the region, underscore the need for effective management. Small national economies with a high dependence on licence fees from purse-seine fleets (FFA 2016) are likely to be vulnerable to these changes by 2050. It is possible, however, that the plans to improve the value of tuna in the 'Regional roadmap for sustainable Pacific fisheries' could maintain existing levels of government revenue from licence fees even though catches decline. The economies of PNG and Solomon Islands are expected to have low vulnerability because tuna fishing and processing make relatively small contributions to the gross domestic product (GDP) of these relatively large economies.

Recommended adaptations

Priority adaptations to maintain the contributions of purse-seine fishing to economic development are based around continuing to: 1) maintain licence revenue and distribute it equitably among PNA members and other Pacific Island countries and territories; 2) deliver the tuna required by existing and proposed canneries in the region; and 3) finding ways to add more value to the abundant skipjack tuna. These adaptations are summarised in Table 1. Two of the key adaptations are already in place. The Vessel Day Scheme, operated by the PNA office, allows licence revenues to be shared among its member countries regardless of the prevailing El Niño Southern Oscillation (ENSO) phase, and adjusts the fishing days allocated to members as climate change alters the distribution of tuna. The Interim Economic Partnership Agreement with the European Union enables PNG to source tuna for national canneries from outside its EEZ, guaranteeing sufficient tuna for processing as the fish move eastward. If needed, other adaptations that would help maintain the supply of tuna for canneries include reducing access for distant-water fishing nations (DWFNs) to PNG's EEZ to provide more fish for national vessels, and requiring DWFNs operating within the EEZ to land fish at local canneries. Finding ways to add more value to skipjack tuna would allow countries to earn more from this resource in the short-term, and help offset the consequences of lower projected catches caused by climate change.

1.2 Effects of climate change on small-scale fisheries

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

Climate change and ocean acidification are projected to have a range of substantial direct and indirect effects on the distribution and abundance of demersal fish and invertebrates in the WCPO. The indirect effects will occur through changes to coastal fish habitats (Section 14.2.2). The main direct effects are summarised below.

Higher SST is expected to alter the metabolic rates, growth, reproduction and survival of demersal fish and invertebrates, resulting in changes in their abundance, size and distribution. Alterations to the strength of ocean currents are likely to affect the dispersal of larvae, thereby reducing recruitment success in some locations and improving success in others. Ocean acidification has been demonstrated to affect the behaviour, auditory responses and olfactory function of early life-history stages of demersal fish species. These changes are expected to alter the homing and settlement success of juveniles and their ability to detect and avoid predators, with implications for population replenishment.

[6] The Parties to the Nauru Agreement are Federated States of Micronesia, Kiribati, Palau, Papua New Guinea, Marshall Islands, Nauru, Solomon Islands and Tuvalu; more than 90% of the tuna caught from the waters of Pacific Island countries and territories comes from the EEZs of PNA members.

Table 1. Examples of priority adaptations and supporting policies to assist Pacific Island countries and territories reduce the threats posed by climate change to the contributions of industrial tuna fisheries to economic development, and capitalise on the opportunities. These measures are classified as 'win-win' (W-W) adaptations, which address other drivers of the sector in the short term and climate change in the long term, or 'lose-win' (L-W) adaptations, where benefits are exceeded by costs in the short term but accrue under longer-term climate change.

Adaptation options	Supporting policies
• Full implementation of the vessel day scheme (VDS) to control fishing effort by the Parties to the Nauru Agreement (W-W). • Diversify sources of fish for canneries and maintain trade preferences; for example, an Economic Partnership Agreement with the European Union (W-W). • Identify ways to add more value to skipjack tuna (W-W). • Continued conservation and management measures for all species of tuna to maintain stocks at healthy levels and make these valuable species more resilient to climate change (W-W). • Energy efficiency programmes to assist fleets to cope with oil price rises minimise CO_2 emissions, and reduce costs of fishing farther afield as tuna move east (W-W). • Environmentally-friendly fishing operations (W-W).	• Strengthen national capacity to administer the VDS. • Adjust national tuna management plans and marketing strategies to provide flexible arrangements to buy and sell tuna. • Promote partnerships to process and market skipjack tuna in new ways. • Include addressing the implications of climate change in the management objectives of the WCPFC. • Apply national management measures to address climate change effects for subregional concentrations of tuna in archipelagic waters beyond WCPFC's mandate. • Require all industrial tuna vessels to provide operational-level catch and effort data to improve models for projecting redistribution of tuna stocks during climate change.

Source: Bell et al. 2018a.

Estimates of the combined direct and indirect effects of climate change and ocean acidification on the productivity of demersal fish in the region vary from decreases of up to 20% by 2050 and 20–50% by 2100 based on a high AR4 emissions scenario, to decreases exceeding 50% under RCP8.5 for AR5 by 2100 (Asch et al. 2018).

The projected changes to coastal fish habitats are also expected to alter the composition of catches. For example, herbivorous species are likely to be relatively more abundant as coral cover declines and macroalgae increase.

Productivity of invertebrates is projected to decrease by 5% by 2050, and by 10% by 2100 under a high AR4 emissions scenario. In particular, lower aragonite saturation levels are expected to reduce calcification rates for gastropod and bivalve molluscs and echinoderms, thereby reducing their quality and size and making them more vulnerable to predation.

The potential effects of climate change on coral reef fisheries are illustrated by the projections for coral trout (*Plectropomus* spp.), which are heavily fished in northeastern Australia and elsewhere in the WCPO. The combined effects of thermal stress on the physiology of these species and the degradation of reef habitat are expected to threaten the viability and sustainability of commercial fisheries by 2050 at low-latitude locations (even under RCP2.6). At subtropical latitudes, fisheries for coral trout are expected to become increasingly uneconomical towards 2100.

Implications for food security and livelihoods

The implications of climate change for the important role that fish plays in providing food security for Pacific Island people have to be placed in the context of the other factors affecting the availability of fish. In many Pacific Island countries and territories, population growth alone creates a large gap between recommended fish consumption (35 kg/person/year) and sustainable harvests from well-managed coastal fisheries.

Based on the total area of coastal fish habitats and the distance of these habitats from population centres, Pacific Island countries and territories fall into three groups with respect to their capacity to provide the fish needed for food security: 1) those with coastal fisheries expected to meet the increased demand for fish; 2) those with sufficient coastal habitat to produce the fish required, but where transportation of fish to urban centres will be difficult; and 3) those where the total area of coastal fish habitats will be unable to produce the fish required.

There are few implications of the projected decreases in coastal fish production arising from climate change for countries and territories in Groups 1 and 2. Possible exceptions are those outside the equatorial zone, where increases in ciguatera fish poisoning resulting from the degradation of coral reefs could result in localised shortfalls in fish supply. In such circumstances, communities will need to rely more heavily on catching tuna in nearshore waters.

For countries and territories in Group 3, the projected declines of up to 20% in coastal fisheries production by 2050 and up to 50% by 2100 are expected to increase the gap only marginally because the effects of human population growth on the availability of fish per capita are so profound (Table 2). The main implications centre on the need to provide better access to tuna to supply the fish required by growing populations, although developing fisheries for small pelagic fish and expanding pond aquaculture will also be important in some locations (see below). Maximising the number of livelihoods that can be sustained from coastal fisheries resources will involve progressively transferring some fishing effort from demersal fish to tuna and small pelagic fish species, and switching some of the remaining demersal fishing effort from resource 'losers' (e.g. coral-dependent fish species) to resource 'winners' (e.g. herbivorous fish species).

Consequences for fisheries management

The direct and indirect effects of climate change and ocean acidification are expected to increase uncertainty in the replenishment of coastal stocks. Increased uncertainty will require changes to the community-based ecosystem approach to fisheries management (CEAFM) and 'primary fisheries management' approaches (Section 14.1.2) used by Pacific Island countries and territories to keep coastal fisheries resources at sustainable levels. The reorientation of CEAFM that is needed to assist communities with adapting to climate change involves: 1) informing all stakeholders about the risks to fish habitats, stocks and catches, and facilitating their participation in decision-making; 2) supporting the transdisciplinary collaboration needed to monitor the wider fisheries system for climate impacts, and identify practical adaptations; and 3) providing the resources needed to implement climate-informed CEAFM.

The more conservative application of primary fisheries management that is needed to address the increased uncertainty is illustrated in Figure 2. Examples of the types of management changes likely to be needed include revised size limits to account for altered growth rates and maturity schedules, and ensuring that the herbivorous species likely to be favoured by climate change are not overfished. Healthy stocks of herbivores will be needed to ensure that macroalgae do not unduly inhibit the growth and survival of remaining corals.

Vulnerability of fish species, fisheries and communities

The small-scale fisheries underpinning food and livelihoods across the region have a moderate to high vulnerability to climate change because: 1) increases in SST will progressively drive many target species to higher latitudes; 2) degradation of coral reefs is expected to reduce the productivity of those fish species able to remain on reefs; and 3) the majority of the small-scale catch is derived from coral reefs.

In turn, many Pacific Island communities are highly vulnerable to decreases in productivity of demersal fish and invertebrates because they have few other sources of animal protein. A participatory approach is needed to raise awareness of the risks, and identify practical adaptations to provide nutritious food for growing human populations. The IPCC vulnerability framework and the Vulnerability Assessment and Local Early Action Planning Tool developed by the US Coral Triangle Initiative have been incorporated into such an approach for communities (Johnson et al. 2016). This approach will be strengthened by assisting communities with evaluating alternative sources of fish (e.g. through development of freshwater pond aquaculture and increasing access to tuna in nearshore waters).

Table 2. Projected gap between recommended fish consumption of 35 kg/person/year, and the estimated annual supply of fish per capita from coastal fisheries in 2050 and 2100 for selected Pacific Island countries due to the effects of population growth (P) and the combined effects of population growth and climate change (CC) under a high emissions scenario.

	Estimated sustainable catch (t)*	Population**		Total fish available per capita (kg)		Gap in fish needed per capita per year (kg)			
						2050		2100	
		2050	2100	2050	2100	P	CC	P	CC
Papua New Guinea	83,500	13,271,000	21,125,000	6	4	29	29	31	32
Samoa	6,100	210,000	240,000	29	25	6	11	10	16
Solomon Islands	27,600	1,181,000	1,969,000	23	14	12	15	21	24
Vanuatu	3,800	483,000	695,000	8	6	27	28	29	30

* Estimates assume sustainable median fisheries production of 3 t/km^2 of coral reef per year (but also include freshwater fisheries production for Papua New Guinea and Solomon Islands, and reef habitat to depth of 100 m for Samoa).
** Estimates provided by the Pacific Community's Statistics for Development Division.

Many Pacific Island communities are highly vulnerable to decreases in productivity of demersal fish and invertebrates because they have few other sources of animal protein. Going fishing, Kiribati, 2018. Image: Francisco Blaha, www.franciscoblaha.info

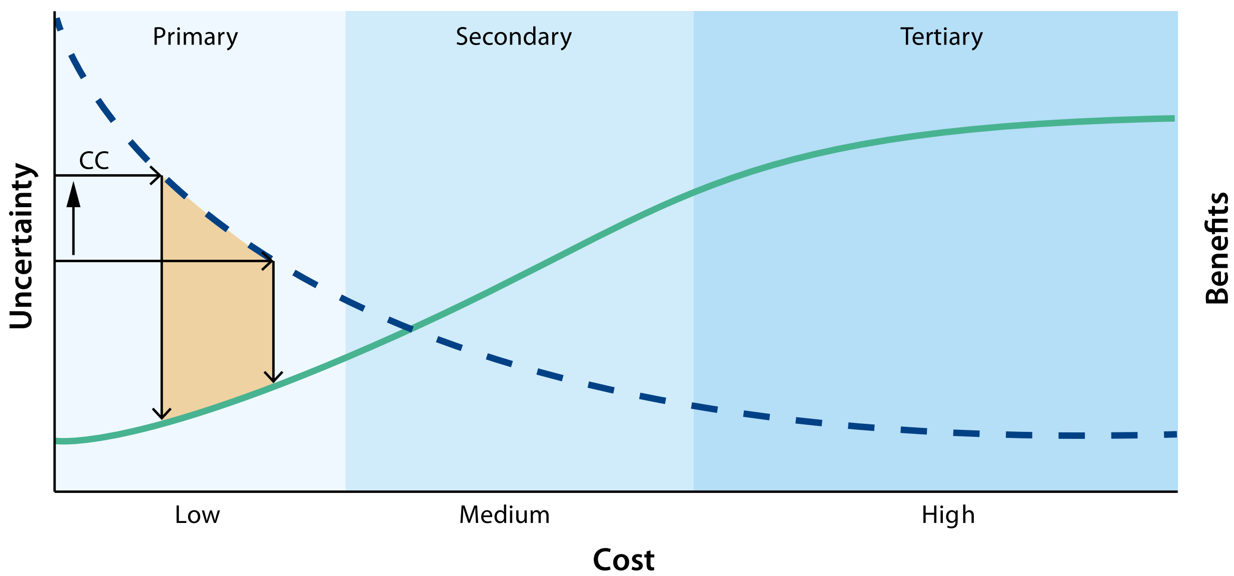


Figure 2. General relationship between potential benefits from fisheries for coastal demersal fish species and invertebrates (green line), and uncertainty in information for management (dashed line), as functions of costs, for primary, secondary and tertiary fisheries management; and the reduction in benefits under primary fisheries management as a result of the increased uncertainty caused by climate change (CC). Source: Bell et al. 2011; Cochrane et al. 2011.

Recommended adaptations

The priority adaptations to maintain the contribution of small-scale fisheries to food security and livelihoods of coastal communities involve finding ways to: 1) minimise the gap between sustainable harvests from coral reefs and other coastal fish habitats and the quantities of fish recommended for good nutrition of growing human populations; and 2) fill the gap (Table 3). Adaptations to minimise the gap centre on avoiding and reversing the degradation of coastal fish habitats and maintaining healthy stocks of demersal fish and invertebrates. Most of these adaptations are an integral part of coastal zone management and sustainable fisheries management (FAO 2003, 2015). Climate-informed, ecosystem-based approaches to fisheries management provide the most effective way forward. Adaptations to fill the gap will need to focus largely on making it easier for small-scale fishers to access the region's rich tuna resources, developing fisheries for small pelagic fish, expanding pond aquaculture, and improving supply chains to avoid waste.

Table 3. Examples of priority adaptations and supporting policies to assist Pacific Island countries and territories with reducing the threats posed by climate change to the contributions of small-scale fisheries to food security and livelihoods of coastal communities, and capitalise on opportunities. These measures are classified as 'win-win' (W-W) adaptations, which address other drivers of the sector in the short term and climate change in the long term, or 'lose-win' (L-W) adaptations, where benefits are exceeded by costs in the short term but accrue under longer-term climate change. Source: Bell et al. 2018 a, b.

Adaptation	Supporting policies
Adaptations to minimise the gap	
• Manage and restore vegetation in catchments (W-W) • Avoid (and reverse) degradation of coastal fish habitats (W-W) • Provide for landward migration of coastal fish habitats (L-W) • Reduce catches to help sustain production of coastal demersal fish and invertebrates (L-W) • Maximise the efficiency of spatial management (W-W) • Diversify catches of coastal demersal fish (L-W)	• Improve governance for sustainable use and protection of coastal fish habitats • Strengthen fisheries legislation to apply community-based management, founded on an ecosystem approach and primary fisheries management • Enhance national regulation of small-scale, commercial fishing • Promote access to those groups of fish expected to increase in abundance • Limit export of demersal fish • Develop ecotourism to relieve fishing pressure on demersal fish stocks
Adaptations to fill the gap	
• Transfer coastal fishing effort from demersal fish to tuna and other large pelagic fish in nearshore waters (W-W) • Expand fisheries for small pelagic species (W-W)* • Extend the storage time of nearshore pelagic fish catches (W-W) • Increase access to small tuna and bycatch offloaded by industrial fleets during transshipping operations (W-W) • Expand aquaculture of Nile tilapia and milkfish (W-W)	• Include nearshore FADs as part of the national infrastructure for food security • Transfer some access rights and revenues from industrial tuna fisheries to small-scale fisheries • Evaluate whether industrial fishing exclusion zones provide adequate access to tuna for small-scale fishers • Apply targeted subsidy programs to support key adaptations • Limit tilapia farming to catchments with a shortage of fish and where tilapia are already established to reduce potential risks to biodiversity

* Small pelagic fish are expected to be favoured by climate change only where changes to currents and eddies deliver more nutrients to surface waters.

Source: Bell et al. 2018 a,b.

2 Key messages from FAO Fisheries and Aquaculture Technical Paper 627

Importance of fisheries and aquaculture

Excluding aquatic plants, total global production from fisheries and aquaculture peaked at 171 million tonnes in 2016, with 53% of this total coming from capture fisheries and 47% from aquaculture (FAO 2018b). Globally, the combined production from fisheries and aquaculture makes substantial contributions to the food security and livelihoods of millions of people. Average fish consumption worldwide is now >20 kg/person/year and an estimated 200 million people are employed directly and indirectly in the fisheries and aquaculture sector (FAO 2018b). Livelihoods sustained by fisheries and aquaculture activities are especially important to many poor communities in coastal, riverine, insular and inland regions.

Approach

The full Technical Paper uses an end-to-end approach to assess the vulnerability of marine and inland fisheries, and aquaculture to climate change. Information is presented on the projected changes in atmospheric climate, the ocean, ecosystems supporting fisheries and aquaculture, the direct and indirect effects of these changes on fisheries and aquaculture production systems, the implications for food security and livelihoods, and practical tools for effective adaptation.

Observed and predicted changes in air temperature

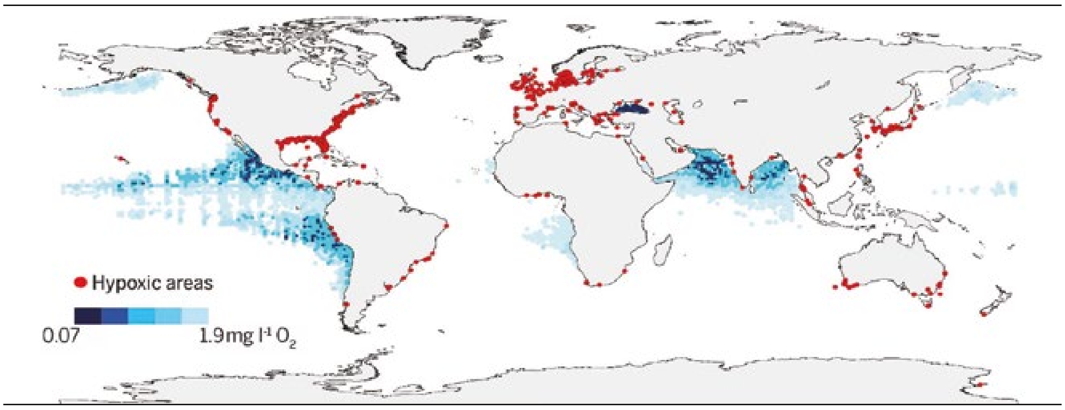
The Earth's average surface air temperature has increased by more than 0.8°C since the middle of the 19th century, and is now warming at a rate of more than 0.1°C every decade. Projected changes in surface air temperature by 2100 vary, depending on a number of social and economic assumptions (e.g. possible future trends in population size, economic activity, lifestyle, energy use, land use patterns, technology, climate policy). Several of the possible scenarios have been summarised into four representative concentration pathways (RCPs) for GHG emissions in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2014). These four RCPs are based on radiative forcings of +2.6, +4.5, +6.0 and +8.5 Watts/m^2. For all RCP scenarios, except RCP2.6, global average surface air temperature is likely to exceed 1.5°C by 2100 relative to the average for the 1850–1900 period, and by 2°C for RCP6.0 and RCP8.5.

Observed and predicted changes in rainfall

The warming of the climate has significant implications for the hydrological cycle. Observed changes in rainfall patterns since 1900 vary across regions. However, modeling indicates that rainfall is very likely to increase in high latitudes and near the equator, and decrease in the subtropics. The frequency and intensity of heavy rainfall events over land are also likely to increase in the near term, although this trend will not be apparent in all regions because of natural variability. For example, droughts are expected to be longer and more frequent in California, the Mediterranean basin, and in existing arid zones.

Observed and predicted impacts to the ocean

The surface waters of the world's oceans (0–700 m deep) have warmed by an average of 0.7°C per century since 1900. This has happened because the ocean absorbs heat from the atmosphere – more than 90% of the additional heat in the atmosphere generated between 1971 and 2010 has been taken up by the ocean. Nevertheless, ocean temperature trends vary among regions and have been most prominent in the Northern Hemisphere, especially the North Atlantic. Because the ocean absorbs >90% of atmospheric heat, SST is expected to approximate the projected increases in surface air temperatures described above. Increases in SST have knock-on effects on dissolved oxygen levels, which have decreased in surface waters due to ocean warming, resulting in an expansion of tropical 'oxygen minimum zones' in recent decades (Fig. 3).



Source: Breitburg et al., 2018

Figure 3. Coastal areas with oxygen deficiency (hypoxia – red dots) and ocean oxygen minimum zones at a depth of 300 m (blue shading). Source: Breitburg et al. 2018.

Increases in SST will strengthen the stratification of the water column, thus reducing the transfer of nutrient-rich waters to the photic zone to support the primary productivity at the base of the food web that underpins marine fisheries. There is also concern that climate change could disrupt the patterns of ocean circulation that redistribute heat and freshwater across the globe, thereby influencing local climates and the important areas of upwelling that drive the productivity of major fisheries. Any changes to the strength, timing and geographical variability of the eastern boundary upwelling systems in the Pacific and Atlantic oceans would have significant effects on some of the world's most productive fisheries.

Sea level is rising mainly due to ocean warming and the melting of land ice, and has risen globally by a mean of 0.19 m since 1900. The rate of sea-level rise varies across regions, however. For example, the rate in the western Pacific is three times the global average but the rate is null or negative in the eastern Pacific. Global average mean sea level is very likely to rise by 0.5 to 1.2 m under RCP8.5, 0.4–0.9 m under RCP4.5, and 0.3–0.8 m under RCP2.6.

Since the beginning of the industrial era, the pH of ocean surface water has decreased by an average of 0.1 due to the absorption of human-produced CO_2. This corresponds to a 26% increase in ocean acidification, causing a decrease in the saturated mineral forms of calcium carbonate ($CaCO_3$) in sea water needed by many marine species to build their shells (e.g. molluscs) and skeletons (e.g. corals). Since 1970, 30% of the additional CO_2 in the atmosphere has been absorbed by the ocean. Average global ocean pH is expected to increase by 0.3–0.4 by 2100 under RCP8.5 (Fig. 4).

Climatic variability and climate change

Interactions between climatic variability (e.g. El Niño Southern Oscillation, ENSO), and climate change can be expected to occur. However, there is still debate about the extent to which ENSO is likely to be affected by climate change. ENSO is the interaction between the atmosphere and ocean in the tropical Pacific that results in three- to seven-year periodic oscillations between particularly warm and cold temperatures for surface waters of the equatorial Pacific, referred to as El Niño and La Niña events, respectively. The release of heat from the ocean to the atmosphere during El Niño events causes changes in global atmospheric circulation, cyclone and hurricane patterns, monsoons, and heating and rainfall trends linked to droughts and floods. ENSO has consequences for ecosystems and species that sustain fisheries, resulting in noticeable increases or decreases in marine fish catches in given areas and a greater frequency of harmful algal blooms (HABs). In many inland ecosystems, the droughts caused by El Niño can result in insufficient water for fisheries and aquaculture.

Climate change impacts on marine capture fisheries

The modelling done for the FAO Technical Paper (Chapter 4) indicates that the average total maximum catch potential in the world's EEZs is likely to decrease by approximately 3–5% by 2050 (relative to 2000) under RCP2.6, and by 7–12% under RCP8.5. The projected decrease does not change much by 2100 under RCP2.6 but is expected to increase 16–25% by 2100 under RCP8.5. However, these projections vary significantly across regions and the impacts are expected to be much greater for some parts of the world. In particular, the greatest decreases in catch potential are likely to occur in the EEZs of countries in the tropics (Fig. 5). In contrast, catch potential for the high-latitude regions is projected to increase, or to decrease less than in the tropics. These projections do not reflect potential changes that may result from current catch levels or the outcomes of fisheries management measures that could potentially be applied to reverse or counter these trends. Rather, they indicate changes in the capacity of the oceans to produce fish in the future compared to their current capacity.

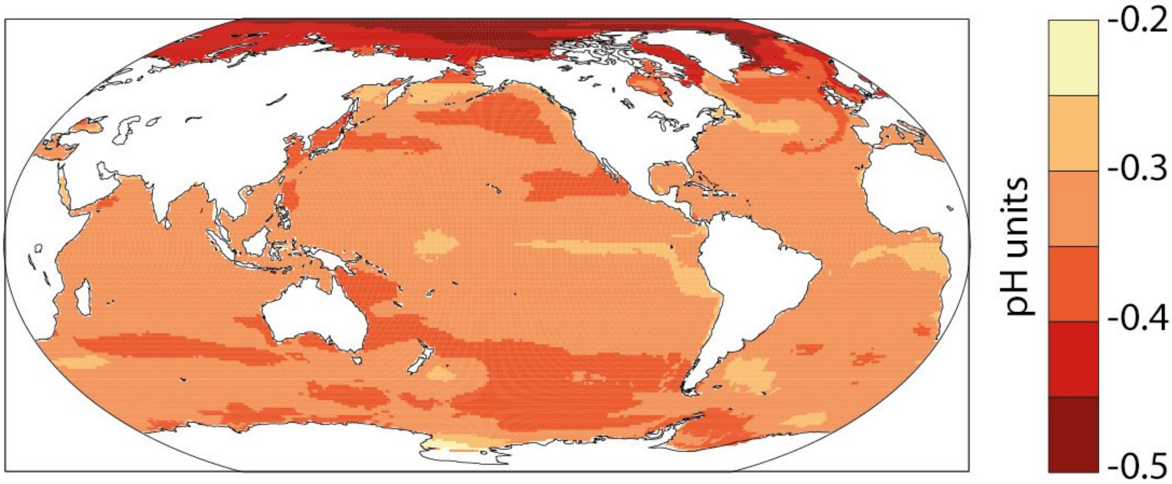


Figure 4. Projected decrease in surface pH from 1850 to 2100 resulting from expected changes in ocean acidification under RCP8.5. Source: Ciais et al. 2013.

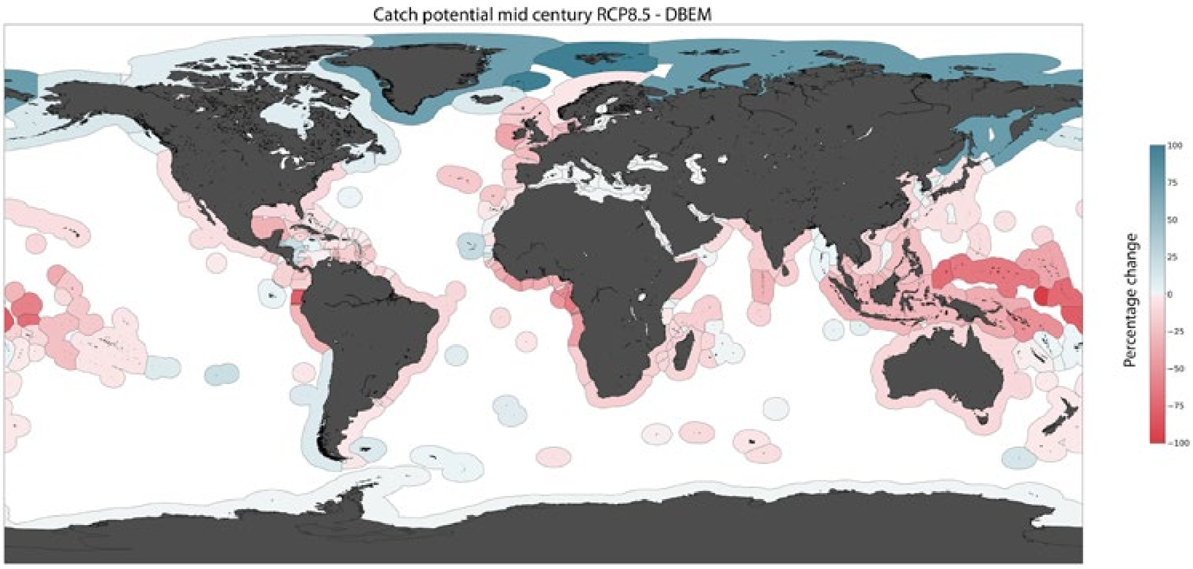


Figure 5. Projected changes in maximum catch potential (%) within national exclusive economic zones under RCP8.5 by 2050 (2046 to 2055), based on the Dynamic Bioclimate Envelope Model. Source: FAO 2018a.

The various case studies on the implications of climate change for marine capture fisheries from many regions of the world (Chapters 5–17) complement the model results. Collectively, they provide unequivocal evidence of the significant impacts that climate change has already had on marine fisheries and reflect the variability and patchiness of responses across the globe.

Climate change impacts on inland fisheries

Over 11 million tonnes of fish were caught by inland fisheries in 2015, equivalent to 12% of total production from all capture fisheries. Inland fisheries catches provide high-quality, affordable food and livelihoods for tens of millions of people, including some of the poorest and most vulnerable people in the world.

Predictions of the impacts of climate change on inland fisheries are difficult to make because they are often confounded with impacts from other sectors that compete with inland fisheries for the use of freshwater. The multiple and high demands for water are expected to increase with human population growth and development. Unless urgent remedial action is taken, the many other uses of freshwater will have serious negative impacts on inland fisheries and the benefits they provide. Unfortunately, in the competition for this scarce resource, the valuable contributions of inland fisheries are often unrecognised or under-valued.

Although there is high likelihod that changes in rainfall patterns and rising inland water temperatures, driven by the increases in surface air temperatures, will lead to alterations in the distribution and abundance of inland freshwater fisheries species, non-climate stressors are expected to be more serious threats to inland fisheries than climate stressors in the decades ahead.

Climate change impacts on aquaculture

Climate change can have direct and indirect, and short- and long-term, impacts on both freshwater and marine aquaculture. Examples of short-term impacts include loss of production and infrastructure arising from extreme events such as floods, and increased risk of diseases, parasites and HABs due to warmer temperatures. Climate-driven changes in surface air temperature, rainfall and SST, ocean acidification, incidence and extent of hypoxia, sea-level rise, availability of wild-caught ‘seed’ for grow-out, among others, will have long-term impacts on aquaculture at scales ranging from organisms to farming systems to regions. Although there are likely to be winners and losers at all scales, unfavourable changes are likely to outweigh favourable ones, particularly in developing countries.

Global vulnerability assessments carried out for marine, brackish and freshwater aquaculture provide detailed results by country and present a number of options for adaptation and building resilience, in line with the ecosystem approach to aquaculture. Ultimately, however, it is at the farm level where the greatest needs to reduce vulnerability can be expected to converge. Specific measures to reduce vulnerability at this scale include improvement of farm management and choice of farmed species, environmental monitoring and spatial planning that takes climate-related risks into account, and coordination of prevention and mitigation actions.

The projected reduction in renewable surface water and groundwater resources in most of the dry and subtropical regions is likely to lead to greater competition between aquaculture, agriculture and other sectors. Reducing the vulnerability of aquaculture to climate change will, therefore, require integration of these important activities into holistic, multi-sectoral plans for watershed and coastal zone management.

Impacts of climate-driven extreme events and disasters

A warmer climate can be expected to change the frequency, intensity, timing, duration and location of extreme events such as cyclones. Accordingly, existing approaches to damage and loss assessment from climate-related disasters in fisheries and aquaculture need to be improved. There is an urgent need to invest in coherent and convergent disaster risk reduction and adaptation measures to anticipate and reduce the impacts of extreme events affecting fisheries and aquaculture. The sector needs to shift from reactive management after disasters have occurred to proactive risk reduction of climate risks and hazards.

Hazards in food safety and aquatic animal health

Climate change is affecting the growth rates of marine pathogenic bacteria, the incidence of parasites and food-borne viruses, and the dynamics of aquatic species as intermediate and definitive hosts for pathogens and parasites. Coping with these climate-driven risks to both the quality of food products and animal health will require greater attention to the monitoring of key environmental parameters and implementing effective early warning systems.

Collaboration among stakeholders, including those responsible for aquatic animal health, the marine environment and food safety and public health, will be essential. This also applies to best-practice biosecurity measures, such as improved spatial planning, border controls and emergency preparedness and risk communication. Aquaculture is particularly vulnerable to these hazards due to the need to rear animals in high density environments.

Adaptations for fisheries and aquaculture

A key feature of the FAO Technical Paper is the synthesis of methods and tools for climate change adaptation in fisheries and aquaculture (Chapter 25). This chapter provides a portfolio of recommended adaptation tools and approaches currently available for marine fisheries, inland fisheries and aquaculture. It also provides guidance for selecting, implementing and monitoring the effectiveness of adaptation actions, and limiting maladaptative practices. These adaptation tools fall into three categories, those for: 1) institutions, 2) food security and livelihoods, and 3) risk reduction and management for resilience. Adaptation should be implemented as an iterative process, equivalent in many respects to adaptive management in fisheries (Fig. 6). The vulnerability assessment of fisheries and aquaculture systems, the initial step in this iterative process, should start with determining clear objectives in consultation with key stakeholders. It should also be grounded in the best available science and traditional ecological knowledge.

To the greatest extent possible, the selected priority adaptations should address not only climate change but also other drivers affecting the sector (i.e. they should be 'no regret' or 'win-win' adaptations). Priority adaptations should also be planned and implemented with a sound understanding of the multi-faceted and interconnected complexity of fisheries and aquaculture activities, and the interactions between the sector and the wider natural and human environments. Failure to do this will increase the risks of inefficiency and maladaptation.

Climate change and poverty in fisheries and aquaculture

Many of the people who live in extreme poverty can be found in small-scale fishing and fish farming communities,

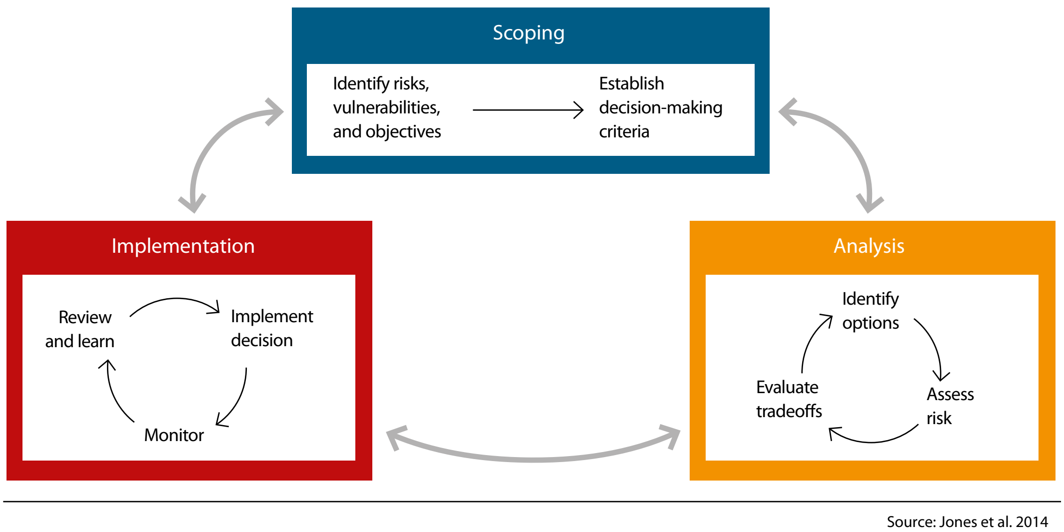


Figure 6. An iterative risk management framework that incorporates system feedback. Source: FAO 2018a.

and are especially vulnerable to climate change because of both their geographic locations and their economic status. Eradicating poverty and ensuring food security is an essential part of increasing the resilience of these communities, as emphasised by the Paris Agreement, the United Nations Agenda 2030, and other international instruments. Tackling climate change through a poverty lens is a key strategy for moving people out of poverty, and for preventing others from becoming poor. Bringing people out of poverty is also essential for making communities more capable of dealing with the impacts of climate change. Achieving these important outcomes requires adaptation to climate change to be multidimensional and multi-sectoral. Poor people impacted by climate change should be provided with flexible practices and opportunities to diversify their livelihoods, allowing them to respond to the challenges of climate change. Active support for adaptation is required at local, national, regional levels of governance. A stronger emphasis should be placed on the contribution of fisheries and aquaculture to poverty reduction and food security in nationally determined contributions of developing countries.

Measures and tools to reduce energy use and emissions

The estimated global emission of CO_2 by all fishing vessels in 2012 was 172.3 megatonnes, which was about 0.5% of total global emissions that year. The aquaculture industry was estimated to have emitted 385 megatonnes of CO_2 in 2010. Overall, however, the energy used for protein production per unit mass of fish is comparable to chicken, but is much less than that from other land-based systems for producing animal dietary protein, such as those for pork and beef. Nevertheless, emission reductions of between 10% and 30% could be attained for marine capture fisheries through the use of more efficient engines and larger propellers on fishing vessels, improvements to vessel design, reducing the mean speed of vessels, and the use of fishing gear that requires less fuel. Opportunities to reduce GHG emissions in aquaculture include improved technologies to increase efficiency in the use of inputs, greater reliance on energy from renewable sources, improved feed conversion rates, and switching from feeds based on fish to feeds made from crop-based ingredients that have a lower carbon footprint. The integration of pond aquaculture with agriculture is also a potential option for reducing fuel consumption and emissions.

3 Concluding remarks

Despite the practicality of the adaptations for industrial tuna fisheries and small-scale fisheries described in Part 1, uncertainty and gaps in knowledge remain about how best to apply them. Staged actions are needed to: 1) identify the research to be done; 2) create effective research partnerships; 3) overcome constraints to sharing knowledge and uptake of technology; and 4) provide economies and communities with the resources needed for effective adaptation. Potential social barriers to the uptake of adaptations recommended for small-scale fisheries (e.g. cultural norms and gender issues that could limit broad-based community participation) also need to be addressed.

Pacific Island countries and territories already recognise the need to build capacity for an integrated approach to climate change adaptation (CCA) and disaster risk management (DRM) (Johnson et al. 2013). Combining DRM and CCA is particularly pertinent in the Pacific Islands region, where there is a large overlap between the most common natural disasters (cyclones) and the impacts of climate change on the fisheries sector. The recent 'Framework for resilient development in the Pacific: an integrated approach to address climate change and disaster risk management' provides strategic guidance for stakeholders about how to enhance resilience to climate change and natural disasters.

Ultimately, one of the most important ways for Pacific Island countries and territories to improve the enabling environment for maintaining the socioeconomic benefits of their marine fisheries will be to prepare, communicate and maintain their nationally determined contributions under the 2015 Paris Agreement to adapt to the impacts of climate change, and reduce national emissions.

The FAO Technical Paper described in Part 2 highlights the variability and complexity of the fisheries and aquaculture sector, and the interactions between the sector and the wider environment. It also shows that the impacts of climate change affect all aspects of the sector – from the underpinning resources through to human well-being – and that efforts to adapt to and mitigate the effects of climate change at all scales should be planned and implemented with full consideration of these complexities.

The onus is also on national and regional agencies to give particular attention to practical adaptations for the most vulnerable people. Otherwise, the vital contributions that fisheries and aquaculture can make to the Sustainable Development Goals related to poverty reduction and food security are likely to be compromised.

These various objectives will be advanced by including the fisheries and aquaculture sector in national climate change policies and instruments, such as the nationally determined contributions or national adaptation plans. Such initiatives should help build the resilience of the ecosystems supporting the sector, and the socioeconomic benefits they provide, and are particularly important for developing countries. Least developed countries and small island developing states can also take advantage of the assistance specifically available to them through climate finance schemes to implement priority adaptations for fisheries and aquaculture.

The entire international community should be encouraged to address the remaining gaps in knowledge about the direct and indirect effects of increased GHG emissions on fisheries and aquaculture. Dismantling this uncertainty will inform progressive improvements to effective adaptation of the sector.

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