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Impacts of climate change on fisheries and aquaculture

Synthesis of current knowledge, adaptation and mitigation options

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Chapter 14: Climate change impacts, vulnerabilities and adaptations: Western and Central Pacific Ocean marine fisheries

Johann D. Bell[1,2], Valerie Allain[3], Alex Sen Gupta[4], Johanna E. Johnson[5,6], John Hampton[3], Alistair J. Hobday[7], Patrick Lehodey[8], Andrew Lenton[7], Bradley R. Moore[9], Morgan S. Pratchett[10], Inna Senina[8], Neville Smith[3] and Peter Williams[3]

1. *Australian National Centre for Ocean Resources and Security, University of Wollongong, Australia*
2. *Conservation International, Arlington, United States of America*
3. *Oceanic Fisheries Programme, Fisheries, Aquaculture and Marine Ecosystems Division, Pacific Community, Noumea, New Caledonia*
4. *Climate Change Research Centre & ARC Centre of Excellence for Climate System Science, University of NSW, Sydney, Australia*
5. *College of Marine and Environmental Sciences, James Cook University, Australia*
6. *C2O Pacific, Cairns, Australia and Port Vila, Vanuatu*
7. *CSIRO Oceans and Atmosphere, Hobart, Australia*
8. *Collect Localisation Satellites, Ramonville, France*
9. *Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia*
10. *ARC Centre of Excellence for Coral Reef Studies, James Cook University, Australia*

KEY MESSAGES

- Continued CO_2 (and other greenhouse gas) emissions are very likely to affect the outcomes of regional and national plans to maintain or improve socio-economic benefits derived from industrial tuna fisheries and small-scale, coastal fisheries.
- Global warming is likely to affect food webs supporting tropical tuna species, and very likely to cause changes in distribution and abundance of tuna by 2050 under the RCP8.5 emissions scenario.
- Redistribution of tropical tuna is very likely to affect licence revenues from purse-seine fishing, and shift more fishing into high seas areas.
- Harvest strategies for tropical tuna will very likely need to account for changes in distribution and abundance resulting from climate change.
- Priority adaptations to maintain the economic benefits of industrial tuna fisheries will need to focus on interventions to maintain licence revenues, and ensure delivery of fish to local canneries.
- Global warming, extreme events, and ocean acidification are very likely to damage coral reefs and other habitats underpinning small-scale, coastal fisheries for demersal fish and invertebrates.
- Changes to coral reefs and other fish habitats, and the direct effects of CO_2 emissions on fish and invertebrates, are likely to reduce harvests from small-scale, coastal fisheries by up to 20 percent by 2050, and by up to 50 percent by 2100, under the RCP8.5 emissions scenario.
- Climate change is very likely to increase uncertainty in replenishment of coastal fish stocks, requiring a more conservative community-based ecosystem approach to fisheries management.

- Priority adaptations to maintain the benefits of coastal fisheries involve minimizing the gap between sustainable harvests and the fish needed for food security, and filling the gap mainly by increasing access to tuna for small-scale fishers.

14.1 INTRODUCTION

This chapter applies an end-to-end, climate-to-fish-to-fisheries, approach (Bell *et al.*, 2013; Bell, Johnson and Hobday, eds., 2011) to assess the vulnerability of the region's plans to secure and increase the socio-economic benefits from fisheries to climate change and ocean acidification. It begins by summarising the observed and projected changes to the physical and chemical features of the Western and Central Pacific Ocean (WCPO), and how these changes are expected to alter fish habitats. For each of the main types of fisheries in the WCPO, the chapter then explains how the direct and indirect effects of continued carbon dioxide (CO_2) emissions are likely to affect the distribution and abundance of fish stocks; the implications for economic development, government revenue, food security and livelihoods; and the adaptations needed to minimize the threats and maximize opportunities.

The analyses presented here are based on global and regional modelling approaches that use the representative concentration pathways (RCPs) from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), or emission scenarios from the IPCC Fourth Assessment Report (AR4). The likelihood and confidence ratings for the key messages have been attributed using the IPCC method.

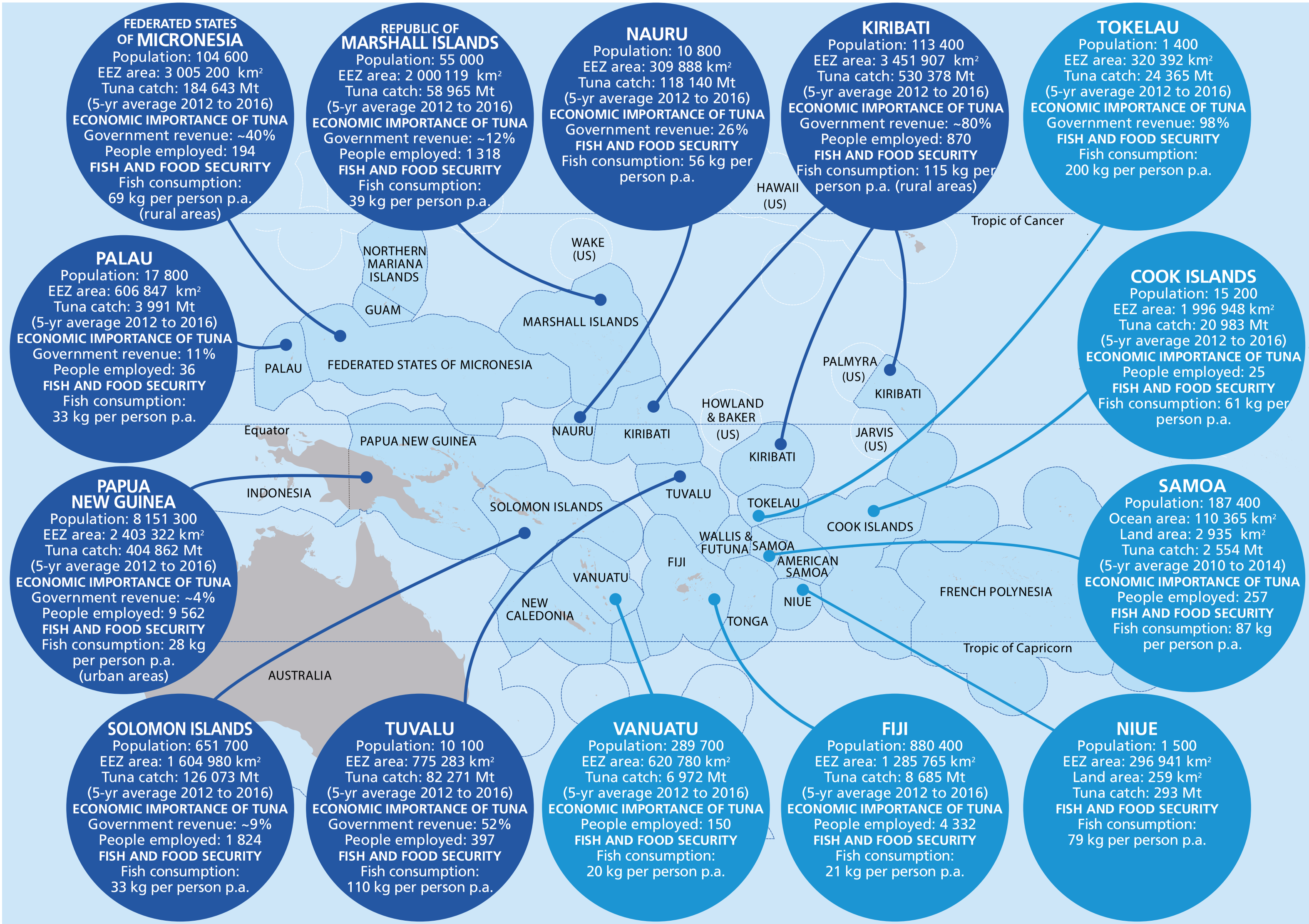
14.1.1 Fisheries of the region

The Western and Central Pacific Ocean[1] supports major industrial tuna fisheries and a variety of small-scale, coastal fisheries. The region's industrial tuna fisheries are the largest in the world, and make substantial contributions to government revenue, gross domestic product (GDP) and employment in several Pacific Island countries and territories (PICTs; Gillett, 2016; Williams, Terawasi and Reid, 2017; Figure 14.1). The industrial surface fishery targets skipjack tuna (*Katsuwonus pelamis*) and juvenile yellowfin tuna (*Thunnus albacares*) using purse-seine and pole-and-line fishing methods to supply canneries in the Pacific, Asia and Europe. The industrial longline fishery targets mature bigeye tuna (*Thunnus obesus*) and yellowfin tuna for the sashimi trade and other high-value markets, and South Pacific albacore (*Thunnus alalunga*) for canning. Around 60 percent of the tuna catch from the WCPO convention area is taken from the exclusive economic zones (EEZs) of PICTs (Williams, Terawasi and Reid, 2017). Industrial tuna fisheries also capture smaller quantities of other large pelagic fish.

Small-scale, coastal fisheries underpin fish consumption and livelihoods in most Pacific Island communities (Figure 14.1; Bell, Johnson and Hobday, eds., 2011; Gillett, 2016). These fisheries target mainly demersal fish and invertebrates associated with coral reefs, mangroves and seagrasses, and increasingly tuna and other large pelagic fish in nearshore waters (Bell *et al.*, 2018; Bell, Johnson and Hobday, eds., 2011; Johnson *et al.*, 2017).

[1] Defined for the purposes of this chapter as the area 25 °N to 25 °S and 130 °E to 130 °W, including Northeastern Australia.

FIGURE 14.1
Key features of selected PICTs and the contributions of fisheries to government revenue, employment and food security



Dark blue circles denote countries that are the Parties to the Nauru Agreement.
Source: Pacific Community and Conservation International.

14.1.2 Strategic plans and management arrangements

Given the great significance of fisheries to Pacific Island people, a concerted effort has been made by PICTs to understand the key drivers of the sector, and to develop strategic plans to secure and increase the socio-economic benefits derived from marine resources. These efforts culminated in the *Regional Roadmap for Sustainable Pacific Fisheries*[2], endorsed by Pacific Island leaders. The Roadmap is designed to 1) optimize the benefits of tuna resources for economic development, government revenue and employment; 2) ensure that growing human populations have enough fish for food security; and 3) sustain livelihoods derived from small-scale fisheries.

The transboundary tuna stocks of the WCPO are managed cooperatively. The Pacific Islands Forum Fisheries Agency (FFA) assists member countries to manage tuna fishing operations by foreign and domestic fleets within their EEZs. The Office of the Parties to the Nauru Agreement (PNA) allocates purse-seine fishing effort across the EEZs of its member countries through the "vessel day scheme". The broader approach needed to co-ordinate tuna catches within EEZs with those made on the high seas is managed by the Western and Central Pacific Fisheries Commission (WCPFC). These management arrangements are based on regular stock assessments for each species of tuna by the Oceanic Fisheries Programme of the Pacific Community (SPC).

SPC and partners support PICTs to manage small-scale fisheries using a community-based, ecosystem approach to fisheries management (CEAFM), underpinned by national regulations to maintain harvests within sustainable bounds (e.g. spatial and temporal fishing closures, size limits and gear restrictions). As a result of increased demand for fish by rapidly-growing human populations in many PICTs, and limits to sustainable harvests from coastal fish habitats, small-scale fishers are also encouraged to catch more tuna from nearshore waters (Bell *et al*., 2015, 2018).

14.2 OBSERVED AND PROJECTED EFFECTS OF CLIMATE CHANGE ON THE WCPO

14.2.1 Effects on physical and chemical features of the ocean

The surface temperature of the WCPO has increased by more than 0.7 °C since 1900 (Bindoff *et al*., 2007). Projections based on a suite of global climate models from the Climate Model Intercomparison Project version 5 (CMIP5) used for AR5 indicate that, under the highly ambitious RCP2.6 emissions scenario, increases in average sea surface temperature (SST) in the WCPO will remain below 1 °C by 2100 relative to 2000 to 2010. However, with increased CO_2 emissions corresponding to the "business-as-usual" RCP8.5 scenario, SST is expected to increase by 2.5 °C to 3.5 °C by 2100 (Table 14.1), and to rise most rapidly in equatorial waters (Figure 14.2). Critically, this long-term warming is expected to cause more extreme marine heat waves, resulting in much higher temperatures over short periods (Hobday *et al*., 2016). The warming ocean, and higher projected rainfall, are expected to increase stratification of the water column, reducing the supply of nutrient-rich water to the surface mixed layer (Bell *et al*., 2013; Bell, Johnson and Hobday, eds., 2011).

Globally, sea level has risen about 20 cm since the industrial revolution (Hay *et al*., 2015). Continued warming of the ocean to a depth of several hundred metres, together with melting of glaciers and ice sheets, is expected to cause sea level to rise by 0.4 m by the end of the century under RCP2.6, and by more than 0.6 m under RCP8.5 (IPCC, 2014).With the possibility of more rapid melting of the ice-sheets (not accounted for in climate models), sea level rise could be considerably greater, exacerbating the effects of storm surges on coastal fish habitats.

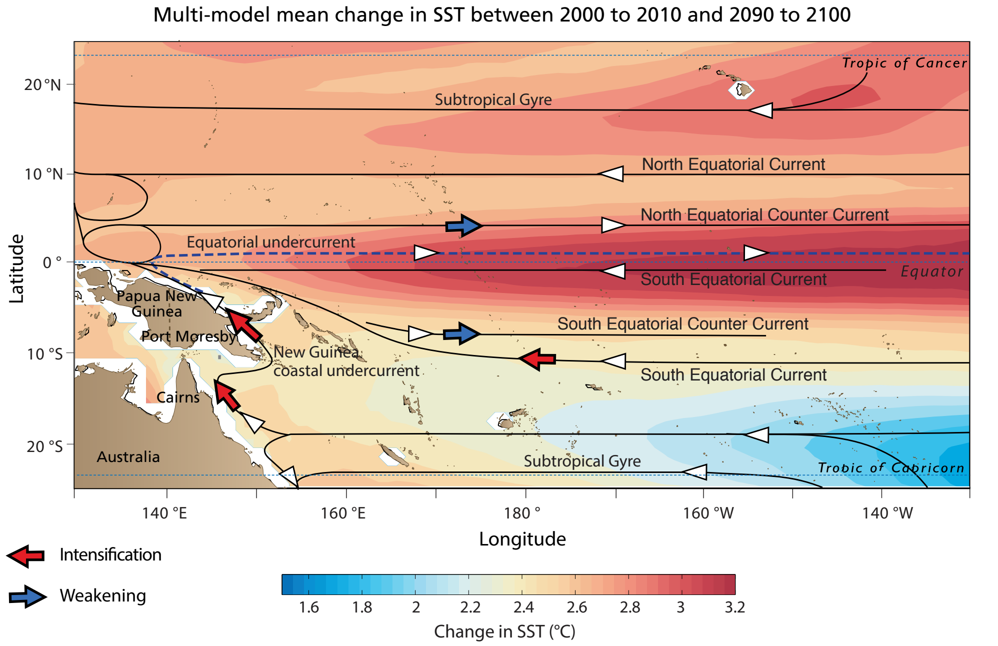
[2] www.ffa.int/node/1569

Increasing rates of ocean acidification in the WCPO through absorption of atmospheric CO_2 (Langlais *et al*., 2017) are reducing the aragonite saturation state, the main form of calcium carbonate used by corals and other marine organisms to build hard skeletons and shells. Since the industrial revolution, ocean acidification has reduced the pH of the upper water column by 0.1 (Royal Society, 2005) and the aragonite saturation level to 3.9 (Langdon and Atkinson, 2005). Aragonite saturation levels greater than 4 are optimal for calcifying organisms, saturation levels between 4 and 3 are marginal to very marginal for calcification, and below 3 complex coral reef systems do not occur (Langdon and Atkinson, 2005). Strong mitigation of CO_2 emissions (RCP2.6), is expected to maintain aragonite levels at approximately 3.5 (Figure 14.3), providing conditions adequate for some coral growth. In contrast, under RCP8.5 it is very likely that aragonite levels in the WCPO will drop below 3 between 2050 and 2100, causing serious degradation of coral reefs.

The CMIP5 simulations indicate that winds and ocean circulation in the region will also change significantly (Table 14.1; Figure 14.2). The northeast and equatorial trade winds are projected to weaken, whereas the southeast trade winds are expected to intensify. The South Equatorial Current and the associated New Guinea Coastal Undercurrent are projected to increase, whereas the velocities of the South Equatorial Counter Current and North Equatorial Counter Current are expected to decrease (Hu *et al*., 2015; Sen Gupta *et al*., 2016; Figure 14.2). In turn, changes in ocean circulation are expected to alter the location and strength of warm and cold eddies that reduce and enhance delivery of nutrient-rich water to the photic zone, respectively (Bell, Johnson and Hobday, eds., 2011).

FIGURE 14.2

Projected mean changes in SST, and major ocean currents (solid lines) and undercurrents (heavy blue dashed line), in the Pacific Island region between 2000 to 2010 and 2090 to 2100. The mean direction of currents is indicated by white triangles



Source: Bell *et al*., 2013.

TABLE 14.1
Multi-model median SST, wind stress, sea level, aragonite saturation and pH from the suite of CMIP5 models averaged over the 2000 to 2010 period, and projected change in these ocean variables by 2050 (2045 to 2055) and 2100 (2090 to 2100) for the RCP2.6 and RCP8.5 emissions scenarios. All changes are expressed as the multi-model inter-quartile range, except for aragonite and pH which are the multi-model median changes

Ocean variable	*Multi-model median 2000 to 2010*	*RCP2.6*		*RCP8.5*	
		2050	*2100*	*2050*	*2100*
Sea surface temperature[1] (°C)	27.4	+0.4–0.8	+0.3–0.8	+0.9–1.3	+2.3–3.3
Maximum warm pool SST, warmest 10% region (°C)	29.4	+0.4–0.8	+0.3–0.8	+0.9–1.3	+2.0–3.1
Warm pool edge, defined by 29 °C isotherm (degrees longitude)	170	180.8–191	179.5–193.3	187–205.3	213.3–EM[3]
Sea level rise (m)	0	+0.28–0.31	+0.4–0.44	+0.36–0.41	+0.6–0.66
Aragonite[1,2]	3.9	-0.32	-0.35	-0.63	-1.43
pH[1,2]	8.07	-0.06	-0.05	-0.12	-0.31
Westward wind stress,					
2 °S–2 °N, 130 °E–230 °W (10^{-4} Nm-2)	-32.6	-0.6– +3.3	0– +4.2	-0.3– +4.5	-2.1– +7.5

[1] Averaged over full domain 25 °S to 25 °N, 130 °E to 130 °W.

[2] Dataset described in Lenton, McInnes and O'Grady (2015).

[3] EM: eastern margin of Pacific basin.

14.2.2 Effects on biological and ecological features of the WCPO

Oceanic food webs

The predicted reductions of nutrients to the mixed layer (Section 14.2.1) have already had negative effects on phytoplankton production at various locations in the tropical and subtropical Pacific Ocean (Boyce, Lewis and Worm, 2010; Signorini, Franz and McClain, 2015). However, modelling of future phytoplankton production, and the knock-on effects on zooplankton and micronekton, indicates that changes in food webs supporting tuna are unlikely to be uniform across the region.

Spatial variability in the effects of increased SST and changes to ocean circulation on oceanic food webs are expected because of differences between the ecological provinces of the region (Bell *et al*., 2013). Impacts are likely to be much lower in the Pacific Equatorial Divergence than in other provinces as a result of strong upwelling. Nevertheless, uncertainty remains. Some modelling suggests that there could be increases in primary production of more than 25 percent in the subtropical North Pacific (Polovina *et al*., 2011). In the western tropical Pacific, other modelling indicates that little change may occur in primary production by 2050 because increases in sub-surface phytoplankton could offset declines in surface phytoplankton (Matear *et al*., 2015).

The considerable uncertainty in how food webs in the WCPO are likely to respond to climate change is related to the complexity of the ecosystem (Bell, Johnson and Hobday, eds., 2011), and to difficulties in encompassing all mechanisms involved when modelling the effects of ocean warming (Evans *et al*., 2015). Improved modelling will depend on a better understanding of prey-predator relationships between different trophic levels (Behrenfeld, 2014), and their autonomous adaptation to environmental change (Schaum *et al*., 2013). Improved simulations of responses of the micronektonic food of tuna to climate change, and collection of better data (including acoustic and environmental DNA data) for model calibration, are particularly important.

The impact of ocean acidification on the food webs supporting tuna has yet to be determined. However, in the productive Pacific Equatorial Divergence, calcareous organisms represent only 1 percent to 5 percent of phytoplankton, approximately 6 percent of zooplankton and 2.2 percent of micronekton (Bell, Johnson and Hobday, eds., 2011). Thus, even severe ocean acidification may have limited impacts at these trophic levels.

Coastal fish habitats

The coral reef, mangrove and seagrass habitats supporting small-scale fisheries in the region are already under stress from climate change and other anthropogenic impacts (Bell, Johnson and Hobday, eds., 2011; Johnson *et al*., 2017). Live coral cover has declined by 1 percent per year since 1980, extensive coral bleaching has occurred on Australia's Great Barrier Reef since 2015 (Hughes *et al*., 2018), and a vast area of mangroves was killed by heat stress in Northern Australia in 2016 (Duke *et al*., 2017).

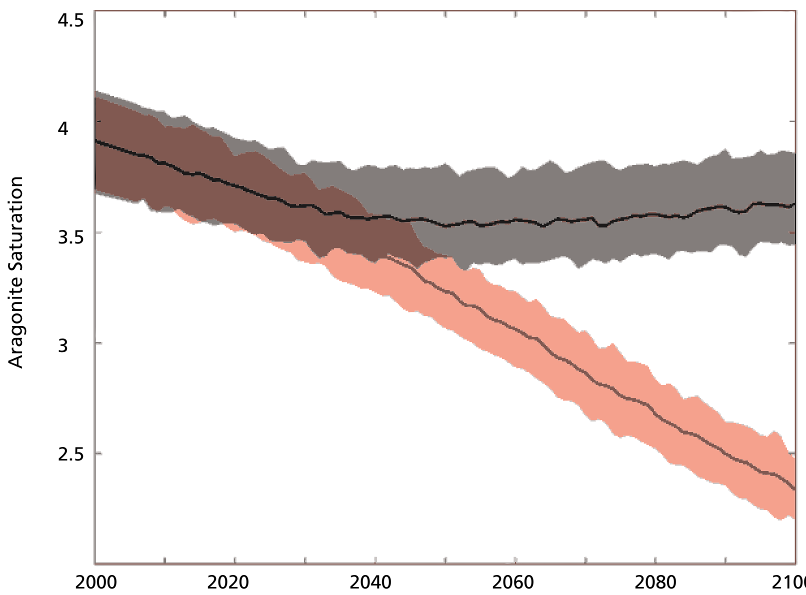
The projected increases in air temperature, turbidity from more extreme rainfall, SST, marine heatwaves, ocean acidification, sea level, and physical damage from more intense cyclones are expected to cause further reductions in the extent and quality of coastal habitats (Bell *et al*., 2013; Johnson *et al*., 2017). Modelling of the future frequency of coral bleaching resulting from increased SST indicates that coral reefs in all PICTs and on the Great Barrier Reef will experience severe annual bleaching by 2050 under the RCP8.5 emissions scenario (van Hooidonk *et al*., 2016).

The combined effects of more regular, severe bleaching and ocean acidification are expected to reduce live coral cover by 50 percent to 75 percent by 2050, and as much as 90 percent by 2100 under a high AR4 emissions scenario (Bell, Johnson and Hobday, eds., 2011). As a result, macroalgae are expected to dominate reefs by 2100.

Sea level rise is expected to cause significant reductions in the area of mangroves because the trees cannot tolerate extended immersion in sea water. The steep terrain of islands in the Western Pacific, where most mangroves in PICTs occur, will prevent landward migration of mangroves as sea level rises in many places. Where the terrain is suitable, rapid sea level rise could outstrip the capacity of mangroves to migrate. By 2050, the area of mangroves across all PICTs could be reduced by 50 percent under a high AR4 emissions scenario (Bell, Johnson and Hobday, eds., 2011). The area of seagrass is also expected to decrease significantly (5 percent to 35 percent) by 2050 across the region under a high AR4 emissions scenario because of increased runoff from more extreme rainfall, as well as increases in cyclone intensity (Bell, Johnson and Hobday, eds., 2011).

FIGURE 14.3

Projected changes in aragonite saturation for the RCP2.6 (grey) and RCP8.5 (red) emissions scenarios averaged across the Pacific Island region until 2100



14.3 EFFECTS OF CLIMATE CHANGE ON INDUSTRIAL TUNA FISHERIES

14.3.1 Observed and projected effects on distribution and abundance

The effects of climate change on tuna[3] have been difficult to observe because of the strong influence of climate variability on their distribution (Hobday and Evans, 2013). Skipjack tuna is a prime example. The locations where the best catches of this species are made in the WCPO can vary by up to 4 000 km of longitude between strong El Niño and La Niña events (Lehodey *et al*., 1997).

Projected responses of tuna in the WCPO to long-term climate change (Figure 14.4), and the combined effects of climate change and potential increased fishing effort, have been modelled using SEAPODYM[4]. An eastward and poleward shift in distribution, and reductions in total biomass, are projected for both skipjack and yellowfin tuna under the RCP8.5 emissions scenario, driven mainly by changes in larval survival and spawning location (Lehodey *et al*., 2013, 2017). Decreases in biomass of these two species in most EEZs west of 170 °E, and increases in EEZs east of 170 °E, are also expected. Projected percentage decreases by 2050 and 2100 relative to 2005 are particularly marked for Papua New Guinea, the Federated States of Micronesia, Nauru and Palau. However, for Papua New Guinea, 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 (Bell *et al*., 2013). 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.

Somewhat different responses are projected for bigeye tuna and South Pacific albacore. For bigeye tuna, strong decreases in biomass are expected to occur in the EEZs of all PICTs, with the declines exceeding 60 percent in several EEZs by 2100 (Figure 14.4). For South Pacific albacore, the distributions of larvae and juveniles are expected to shift south towards the Tasman Sea after 2050 (Figure 14.4). Densities of early life stages are projected to decrease in their core area (Coral Sea) by 2050, resulting in a stabilized adult biomass approximately 30 percent lower than in 2000. However, the North Tasman Sea could emerge as a new spawning ground after 2080, reversing the downward trend in abundance (Lehodey *et al*., 2015).

14.3.2 Comparative effects of non-climate stressors

There are few concerns about the effects of other drivers on the supply of tuna from industrial tuna fisheries. Notwithstanding the need to reduce the impact of tuna fisheries on the ecosystem (FAO, 2003; Pikitch *et al*., 2004), the management arrangements described in Section 14.1 and associated harvest strategies should maintain stocks above the limit reference points for each tuna species.

14.3.3 Implications for economic development

Redistribution of skipjack and yellowfin tuna (Figure 14.4) is expected to result in lower catches across the prime fishing grounds by 2050. Ultimately, reduced catches are also expected to affect licence revenues and the existing plans to increase employment based on industrial fishing and processing in Papua New Guinea and Solomon Islands. This employment risk is tempered, however, by the fact that recent average tuna catches in the EEZs and archipelagic waters of Papua New Guinea and Solomon Islands (see supplementary material in Bell *et al*., 2015) well exceed the capacity of existing and proposed fish-processing facilities. Nevertheless, changes in licencing conditions may be needed to ensure that more of the fish caught within the EEZs of these countries

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[3] For the purpose of this chapter, "tuna" also includes other large pelagic fish, such as wahoo (*Acanthocybium solandri*), mahi mahi (*Coryphaena hippurus*) and billfish (Family Istiophoridae).

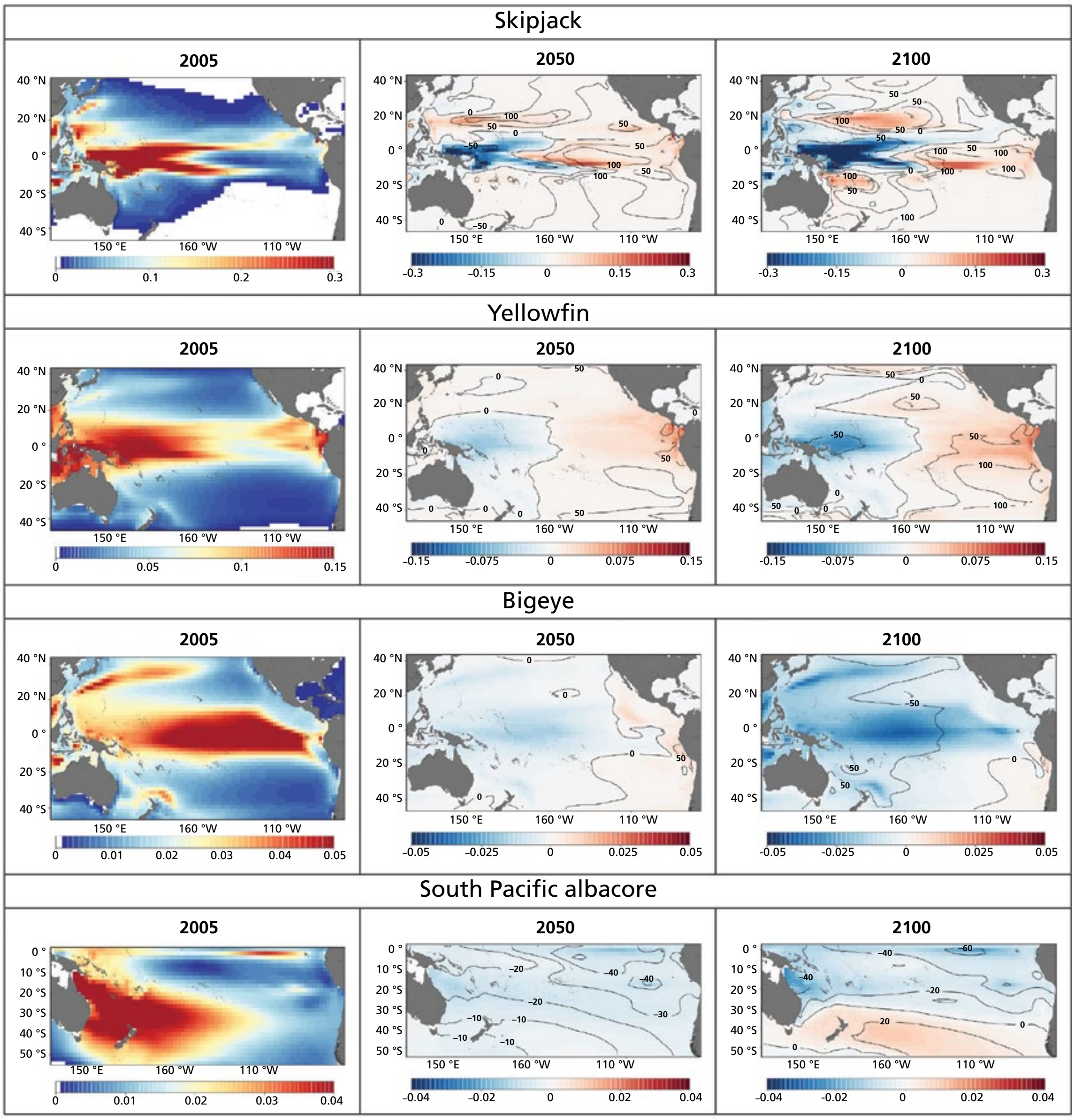
[4] A Spatial Ecosystem and Populations Dynamics Model; https://doi.org/10.1016/j.pocean.2008.06.004

is delivered to national canneries (Section 14.6). Other possible negative impacts on economic development may occur from the eastward redistribution of bigeye tuna and poleward movement of South Pacific albacore (Figure 14.4). In both cases, a greater proportion of longline fishing is eventually expected to occur outside the EEZs of PICTs, reducing government revenue from licence fees.

The projected eastward redistribution of skipjack and yellowfin tuna as a result of climate change could result in opportunities for PICTs in the eastern WCPO, e.g. French Polynesia, and PICTs in the subtropics, e.g. 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.

FIGURE 14.4

Average historical (2005) distributions of skipjack, yellowfin and bigeye tuna and South Pacific albacore (Mt/km²) 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



14.3.4 Consequences for fisheries management

The modelling summarized in Section 14.3.1 indicates that an increase in fishing effort will exacerbate the overall decreases in production of tuna species projected to occur as a result of climate change. To minimize negative effects on tuna catches, fishing effort will need to be constrained and future harvest strategies adjusted to account for alterations in distribution and abundance of tuna species. The depletion-based reference points used by WCPFC are well suited to adjusting management to cater for possible future changes in stock productivity because biomass levels are considered in relation to levels that would have occurred in the absence of fishing. Other possible consequences include 1) the need to transfer more management responsibility to WCPFC as a greater proportion of the catch is made in high seas areas; and 2) 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 FFA, PNA and WCPFC should help identify if and when such a change 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 (Williams, Terawasi and Reid, 2017), management will also need to ensure that the effects of FAD fishing on associated species (e.g. sharks) and juvenile bigeye tuna (Hall *et al*., 2017) are mitigated effectively.

14.3.5 Vulnerability of fisheries and economies

The four species of tropical tuna 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 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 warm pool (see Table 14.1 for definition) during El Niño events, when shoaling of the thermocline contracts the vertical habitat for this species (Johnson *et al*., 2017). Increased vulnerability to capture by the surface fishery, and projected decreases in availability of these two species across much of the region (Section 14.3.1), underscore the need for effective management (Section 14.4.3). The small national economies with a high dependence on licence fees 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 Roadmap could maintain existing levels of government revenue from licence fees even though catches decline. The economies of Papua New Guinea and Solomon Islands are expected to have low vulnerability because tuna fishing and processing make relatively small contributions to GDP of these relatively large economies.

14.3.6 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 PICTs; 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 summarized in Table 14.2 and described in more detail in Bell, Johnson and Hobday, eds. (2011).

Two of the key adaptations are already in place. The VDS (Section 14.1.2) allows licence revenues to be shared among PNA member countries regardless of El Niño-Southern Oscillation phase and adjusts the fishing days allocated to countries as climate change alters the distribution of tuna. The Interim Economic Partnership Agreement with the European Union enables Papua New Guinea 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 Papua New Guinea'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 PICTs to earn more from this resource in the short-term, and help offset the consequences of lower projected catches caused by climate change.

TABLE 14.2
Examples of priority adaptations and supporting policies to assist PICTs reduce the threats posed by climate change to the contributions of industrial tuna fisheries to economic development, and capitalize 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 (Chapter 25)

<table>
<tr><th>Adaptation options</th><th>Supporting policies</th></tr>
<tr><td>Full implementation of the vessel day scheme (VDS) to control fishing effort by the Parties to the Nauru Agreement[a] (W-W).</td><td rowspan="6">• Strengthen national capacity to administer 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 implications of climate change in 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.</td></tr>
<tr><td>Diversify sources of fish for canneries and maintain trade preferences, e.g. an Economic Partnership Agreement with the European Union (W-W).</td></tr>
<tr><td>Identify ways to add more value to skipjack tuna (W-W).</td></tr>
<tr><td>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).</td></tr>
<tr><td>Energy efficiency programmes to assist fleets to cope with oil price rises, minimize CO_2 emissions, and reduce costs of fishing further afield as tuna move east (W-W).</td></tr>
<tr><td>Environmentally-friendly fishing operations (W-W).</td></tr>
</table>

Source: Bell *et al*., 2013, Bell, Johnson and Hobday, eds., 2011.

[a] = The Parties to the Nauru Agreement (PNA) are Palau, Federated States of Micronesia, Papua New Guinea, Solomon Islands, Marshall Islands, Nauru, Kiribati and Tuvalu; more than 90% of the tuna caught from the waters of PICTs comes from the EEZs of PNA members.

14.4 EFFECTS OF CLIMATE CHANGE ON SMALL-SCALE FISHERIES

14.4.1 Observed and projected effects on distribution and abundance

Declines in abundance of coral reef fishes because of coral bleaching have been observed on the Great Barrier Reef (Pratchett *et al*., 2011). However, climate change and ocean acidification are projected to have a greater range of direct and indirect effects on distribution and abundance of demersal fish and invertebrates in the WCPO. The indirect effects will occur through changes to coastal fish habitats. The main direct effects are summarized 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 (Asch, Cheung and Reygondeau, 2018; Munday *et al*., 2008). Alterations to the strength of ocean currents are likely to affect the dispersal of larvae, reducing recruitment success in some locations and improving success in others (Bell, Johnson and Hobday, eds., 2011). Ocean acidification has been demonstrated to affect the behaviour (Munday *et al*., 2013), auditory responses (Simpson *et al*., 2011) and olfactory function (Dixson, Munday and Jones, 2010) 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 (Munday *et al*., 2013), with implications for population replenishment. Lower aragonite saturation levels are expected to reduce calcification rates for gastropod and bivalve molluscs and echinoderms, making juveniles more vulnerable to predation (Bell, Johnson and Hobday, eds., 2011).

The combined direct and indirect effects of climate change and ocean acidification are estimated to reduce productivity of demersal fish in the region by up to 20 percent by 2050, and by 20 percent to 50 percent by 2100, under a high AR4 emissions scenario (Bell, Johnson and Hobday, eds., 2011). The projected changes to coastal fish habitats (Section 14.2.2 – 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 (Bell, Johnson and Hobday, eds., 2011). Recent modelling of expected changes in abundance and distribution of demersal fish in the tropical Pacific indicates that even greater decreases in production may occur, exceeding 50 percent under RCP8.5 by 2100, especially in the west of the region (Asch, Cheung and Reygondeau, 2018).

Productivity of invertebrates is projected to decrease by 5 percent by 2050, and by 10 percent by 2100 under a high AR4 emissions scenario, and their quality and size is expected to be affected by reduced aragonite saturation levels (Bell, Johnson and Hobday, eds., 2011).

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 Indo-Pacific. The thermal optimum for *Plectropomus leopardus* is 27 °C to 30 °C (Johansen *et al*., 2014), however, stocks are now exposed to temperatures of more than 30 °C throughout much of their range. Although this species may be able to moderate its exposure and sensitivity to increasing temperatures by moving to deeper water, reducing energetic expenditure and adjusting food intake during periods of higher SST, ocean warming is expected to reduce sustainable harvests, especially at low latitudes (Johansen *et al*., 2015; Pratchett *et al*., 2017). The direct impacts of ocean warming will be compounded by degradation of coral reefs. In combination, these direct and indirect effects are expected to threaten the viability and sustainability of commercial fisheries by 2050 (even under RCP2.6) at low-latitude locations. At subtropical latitudes, fisheries for coral trout are expected to become increasingly uneconomical towards 2100.

14.4.2 Comparative effects of non-climate stressors

Coastal fisheries in the WCPO are expected to be at much greater risk from drivers other than climate change in the near term (Gillett and Cartwright, 2010). The strongest drivers are those associated with rapid population growth (see supplementary material in Bell *et al*., 2015), i.e. overfishing because of limited alternative sources of protein and degradation of fish habitats caused by more intense land use and pollution (Gillett and Cartwright, 2010).

The main challenges are to 1) keep coastal fish and shellfish stocks within sustainable bounds through conservative fisheries management approaches fit for purpose, e.g. primary fisheries management (Cochrane, Andrew and Parma, 2011); and 2) manage coastal fisheries to address the key drivers while simultaneously minimizing the risks to stocks posed by climate change, and capitalizing on opportunities (Section 14.4.6).

14.4.3 Implications for food security and livelihoods

The implications of climate change for the important role that fish plays in local food security have to be placed in the context of the other factors affecting availability of fish. In many PICTs, population growth alone creates a large gap between recommended fish consumption for Pacific Island people (35 kg of fish per person per year) and sustainable harvests from well-managed coastal fisheries (Bell, Johnson and Hobday, eds., 2011).

Based on the area of coastal fish habitats and the distance of these habitats from population centres, PICTs fall into three groups with respect to their capacity to provide the fish needed for food security (Bell, Johnson and Hobday, eds., 2011): 1) PICTs with coastal fisheries expected to meet 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) PICTs where 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 PICTs in Groups 1 and 2. The main risk is for PICTs outside the equatorial zone, where increases in ciguatera fish poisoning as a result of degradation of coral reefs caused by ocean warming could result in localised shortfalls in fish supply (Bell, Johnson and Hobday, eds., 2011). In such circumstances, communities will need to rely more heavily on catching tuna in nearshore waters.

For PICTs in Group 3, the projected declines of up to 20 percent in coastal fisheries production by 2050 and up to 50 percent by 2100 are expected to increase the gap only marginally because the effects of population growth on availability of fish per capita are so profound (Table 14.3). The main implications centre on the need to provide better access to tuna to supply the fish required by growing populations (Bell *et al.*, 2015). Developing fisheries for small pelagic fish (Bell *et al.*, 2018) and expanding pond aquaculture (Johnson *et al.*, 2017) will also be important (Section 14.4.6).

Maximising the number of livelihoods that can be sustained from coastal fisheries resources will involve progressively transferring some effort from demersal fish to tuna and small pelagic fish species (Bell *et al.*, 2018; Bell, Johnson and Hobday, eds., 2011), and switching some demersal fishing effort from resource “losers” to resource “winners”.

TABLE 14.3
Projected gap between recommended fish consumption of 35 kg per person per year, and the estimated annual supply of fish per capita from coastal fisheries, in 2050 and 2100 for selected Pacific Island countries because of the effects of population growth (P) and the combined effects of population growth and climate change (CC) under a high AR4 emissions scenario

Country	*Estimated sustainable catch (Mt)**	*Population***		*Total fish available per capita per year (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	21 125	6	4	29	29	31	32
Samoa	6100	210	240	29	25	6	11	10	16
Solomon Islands	27 605	1 181	1 969	23	14	12	15	21	24
Vanuatu	3 812	483	695	8	6	27	28	29	30

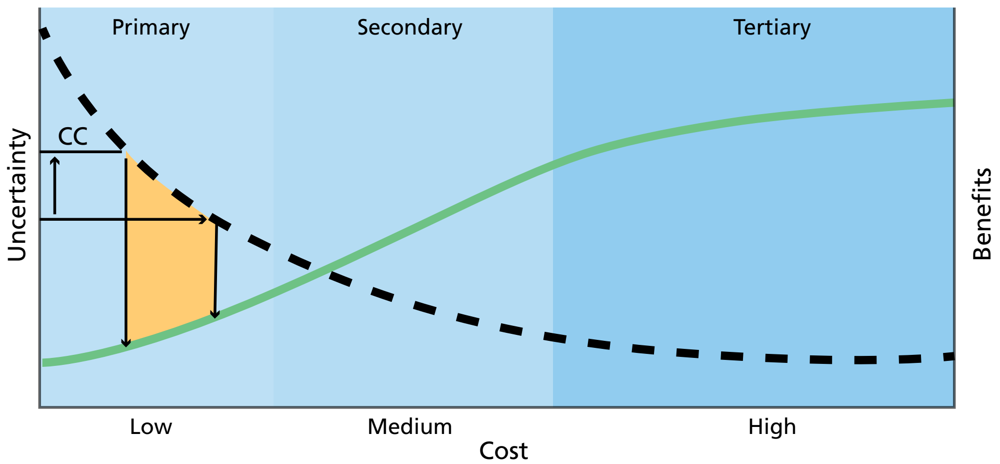
*Estimates assume sustainable median fisheries production of 3 Mt per km^2 of coral reef per year (but also include freshwater fisheries production for Papua New Guinea and Solomon Islands, and reef habitat to depth of 100 m for Samoa).
**Estimates provided by the Pacific Community’s Statistics for Development Division (source: Bell *et al.*, 2013).

14.4.4 Consequences for fisheries management

The direct and indirect effects of climate change and ocean acidification are expected to increase uncertainty in replenishment of coastal stocks (Bell, Johnson and Hobday, eds., 2011). Increased uncertainty will require changes to the CEAFM and primary fisheries management approaches used by PICTs to keep coastal fisheries resources at sustainable levels. The reorientation of CEAFM needed to assist communities to adapt 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 trans-disciplinary 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 (Heenan *et al*., 2015).

The more conservative application of primary fisheries management needed to address the increased uncertainty is illustrated in Figure 14.5. Examples of the types of management changes likely to be needed are 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 (Bell, Johnson and Hobday, eds., 2011).

FIGURE 14.5
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. The reduction in benefits under primary fisheries management as a result of the increased uncertainty caused by climate change (CC) is indicated by the orange shading



Sources: Bell, Johnson and Hobday, eds., 2011; Cochrane, Andrew and Parma, 2011.

14.4.5 Vulnerability of fisheries and communities

The small-scale, coastal fisheries underpinning food and livelihoods across the region have a moderate to high vulnerability to climate change for the following reasons: 1) the majority of the catch is derived from coral reefs (Bell, Johnson and Hobday, eds., 2011); 2) increases in SST will progressively drive many target species to higher latitudes (Asch, Cheung and Reygondeau, 2018); and 3) degradation of coral reefs is expected to reduce the productivity of species able to remain on reefs (Bell, Johnson and Hobday, eds., 2011). Even so, differences in vulnerability of the target species associated with coral reefs are expected between the Pacific Island region and Northeastern Australia. Coral-dependent species in PICTs are highly vulnerable (Table 14.4) because there are significant constraints on latitudinal shifts, mainly as a result of a lack of suitable habitat at higher latitudes. In Northeastern Australia, the vulnerability of reef-dependent fish species is lower because the connectivity of the Great Barrier Reef over 2 300 km should enable them to move to higher latitudes. The vulnerability of reef-associated and generalist species is expected to be moderate to high by 2100 because of their lower sensitivity to reduced live coral cover and structural complexity of reefs.

Many Pacific Island communities have a high vulnerability 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 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 scores and ranks the vulnerability of communities based on their exposure, sensitivity and adaptive capacity, using indicators of health, education, size of the economy and governance. This initiative is complemented by the climate-informed ecosystem approach to fisheries management (Heenan *et al*., 2015), and by assisting communities to evaluate alternative sources of food, e.g. access to freshwater for pond aquaculture and availability of tuna in nearshore waters (Bell, Johnson and Hobday, eds., 2011).

TABLE 14.4
Projected changes in productivity of the main types of demersal fish species associated with coral reefs in the Pacific Island region under a high emissions scenario in 2050 and 2100

Type of species	*2050*	*2100*
Coral-dependent	-90%	-100%
Reef-associated	-20 to -40%	-20 to -80%
Generalist	0%	-10 to -20%
All demersal fish	-20%	-20 to -50%

Source: Bell, Johnson and Hobday, eds., 2011.

14.4.6 Recommended adaptations

The priority adaptations to maintain the contribution of fisheries to food security and livelihoods of coastal communities involve finding ways to 1) minimize the gap between sustainable harvests from coastal fish habitats, and the quantities of fish recommended for good nutrition of growing human populations; and 2) fill the gap (Bell *et al*., 2018; Table 14.5). Adaptations to minimize the gap centre on avoiding and reversing 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 (Heenan *et al*., 2015) 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 (Bell *et al*., 2015, 2018; Johnson *et al*., 2017).

TABLE 14.5
Examples of priority adaptations and supporting policies to assist PICTs reduce the threats posed by climate change to the contributions of small-scale fisheries to food security and livelihoods, and capitalize 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 (Chapter 25)

Adaptation	**Supporting policies**
Adaptations to minimize 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). Sustain production of coastal demersal fish and invertebrates (L-W). Maximize 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.

Adaptation	Supporting policies
Adaptations to fill the gap	
Transfer coastal fishing effort from demersal fish to nearshore pelagic fish (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 trans-shipping 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 programmes 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.

Source: Bell *et al*., 2013, 2018.
*Small pelagic fish are expected to be favoured by climate change only where changes to currents and eddies deliver more nutrients to surface waters.

14.5 CAPACITY DEVELOPMENT AND ENABLING ENVIRONMENT

Despite the practicality of the adaptations for industrial tuna fisheries and small-scale, coastal fisheries outlined above, uncertainty and gaps in knowledge remain about how best to apply them (Bell *et al*., 2013). Staged actions are needed to identify the research to be done; create effective research partnerships; overcome constraints to sharing knowledge and uptake of technology; and provide countries and communities with the resources needed for effective adaptation. Potential social barriers to the uptake of adaptations recommended for small-scale, coastal fisheries, e.g. cultural norms and gender issues that could limit broad-based community participation, also need to be considered.

The region also recognizes the need to build capacity for an integrated approach to climate change adaptation (CCA) and disaster risk management (DRM; Johnson, Bell and De Young, 2013). Combining DRM and CCA is particularly pertinent in the Pacific Island 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*[5] provides strategic guidance for stakeholders about how to enhance resilience to climate change and natural disasters. The Framework builds capacity to prepare for disasters, including those caused or exacerbated by climate change. The disaster preparedness, response and recovery initiatives in the Framework are designed to reduce undue human losses, and minimize adverse consequences for the region's social and environmental systems.

Ultimately, the most important ways for PICTs to improve the enabling environment for maintaining the socio-economic 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 (Chapter 28).

Supplementary material, providing more detail for several aspects of this chapter, can be downloaded at http://oceanfish.spc.int/media/files/Supplementary%20Materials%20Chapter%2014.pdf

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[5] http://gsd.spc.int/frdp/

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