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Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change

Summary for Pacific Island Countries and Territories

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By

Johann D Bell, Johanna E Johnson, Alex S Ganachaud,
Peter C Gehrke, Alistair J Hobday, Ove Hoegh-Guldberg,
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Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change: Summary for Pacific Island Countries and Territories

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Foreword

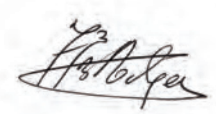
The bonds between the people of the Pacific and their fisheries are extraordinary. Fish and shellfish are common in Pacific folklore and nowhere else do so many countries and territories depend as heavily on fisheries for economic development, food security and livelihoods. These unique relationships underpin the directive of Pacific Islands Forum Leaders to 'develop and implement national and regional conservation and management measures for the sustainable utilisation of fisheries resources' – a priority of the Pacific Plan.

Rapid population growth in many Pacific Island countries and territories demands new approaches to the sustainable use of natural resources for economic, human and social development. A recent study entitled 'The Future of Pacific Island Fisheries' by the Forum Fisheries Agency and Secretariat of the Pacific Community is a valuable guide to optimising the benefits from fisheries and aquaculture. However, achieving these benefits over the long term will depend on our ability to recognise and respond to the many drivers affecting the production and use of fish and shellfish.

There is now little doubt that the impact of climate – already an important driver of fisheries and aquaculture production – is likely to increase in the years ahead. To respond effectively, we need to know the vulnerability of the sector to the changing climate and how best to adapt.

To provide the region with this information, the Secretariat of the Pacific Community has published the peer-reviewed book, *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*, with generous support from the Australian Agency for International Development (AusAID). The purpose of this summary is to present the main results from the regional vulnerability assessment as they apply to each country and territory, making the information easily to use.

The practical adaptations, policies and investments described here are needed to maintain the economic and social benefits of fisheries and aquaculture in the face of climate change. They are essential planning tools. I recommend them to all stakeholders in the fisheries and aquaculture sectors of Pacific Island countries and territories, and their development partners.



Dr Jimmie Rodgers
Director-General
Secretariat of the Pacific Community

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Preface

It is now clear that the global community must do more than plan how to reduce global warming – we must learn to adapt to the inevitable increases in the temperature and acidification of the oceans while we rein in emissions of greenhouse gases. Adaptation has been a focus of recent international climate change negotiations and strong pledges have been made to help developing countries respond to the climate-related changes ahead.

Australia is well aware of the potential effects on yields from agriculture and fisheries likely to occur as a result of climate change. We are deeply committed to helping our Pacific neighbours understand their vulnerability to these changes and how best to respond. Together, we must find ways to maintain the quality of life for all people in the region as the impacts of climate change intensify.

The onus is on everyone involved to make the best use of the technical and financial support available for adaptation. The process should begin with thorough assessments of the vulnerability of the resources that underpin national economies, food security and livelihoods. Only then can sensible adaptations be identified and implemented in a timely and cost-effective way.

The comprehensive analysis provided in the book entitled *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change* now provides the region with the understanding needed, and the adaptations, policies and investments recommended to reduce the likely impacts of climate change on fisheries and aquaculture. It also gives the sector a roadmap for capitalising on the opportunities expected to arise from the changing climate.

This summary, which is a companion to the book, provides this vital information in an accessible form for each Pacific Island country and territory. It will be a valuable planning tool for policy makers, communities and their development partners.

Importantly, the summary is designed so that it can be updated regularly, given that much uncertainty still surrounds climate change projections. Reassessments of projected changes to surface climate, the tropical Pacific Ocean, fish habitats and fish stocks will be needed every 5-7 years to check whether adaptations to maintain the economic and social benefits from the sector are on track or should be realigned. Australia looks forward to contributing to this process.

The Hon Kevin Rudd MP

Minister for Foreign Affairs
Australia

Acknowledgements

This book is the product of a partnership that started between the Australian Agency for International Development (AusAID) and the Secretariat of the Pacific Community (SPC), and then grew to embrace contributions from 36 institutions. The late Gordon Anderson, in his role as the AusAID Pacific Fisheries Programme Development Adviser, was the first person to actively promote the need for a comprehensive assessment of the vulnerability of fisheries and aquaculture in the tropical Pacific. Generous support from AusAID's International Climate Change Adaptation Initiative and strong commitment from the executive team at SPC provided the opportunity to bring this important vision to fruition.

We thank the many other scientists who contributed to writing the chapters of the book *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change* from which this summary was drawn. The heads of fisheries departments in Pacific Island countries and territories, and our fellow members of the technical working group created to guide the project, provided valuable advice on how to compile this summary to meet the needs of policy makers and other stakeholders.

Several other people helped produce this summary. Carla Appel and Boris Colas did a masterful job with the layout to make the technical information easy to digest. Céline Barré was instrumental in deciding how best to present the information and checked the entire content of the summary. Angela Templeton provided valuable editorial advice, Peter Williams and Colin Millar helped summarise the recent tuna catches and Jeff Maynard and Lindsay Chapman assisted with the proof reading. Senior fisheries staff from across the region provided much-appreciated feedback on the proposed content and format of the draft sections for Pacific Island countries and territories at the 7th SPC Heads of Fisheries Meeting.

Finally, we acknowledge the modelling groups at the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the World Climate Research Programme's (WCRP) Working Group on Coupled Modelling (WGCM), for their roles in making available the WCRP CMIP3 multi-model dataset. Their work underpins the vulnerability assessments for fish habitats, fish stocks, and fishing communities and enterprises summarised here.

1. Introduction

Throughout the tropical Pacific, fisheries and aquaculture make vital contributions to economic development, government revenue, food security and livelihoods {Chapter 1}. In recent years, licence fees from distant water fishing nations (DWFNs) have provided 3–40% of government revenue for seven Pacific Island countries and territories (PICTs), and fishing by national industrial fleets and/or fish processing have contributed 3–22% of gross domestic product (GDP) in five PICTs[1] {Chapter 12}. Small-scale coastal fisheries have also provided 2–17% of GDP in five PICTs[1].

The contributions of fisheries to the formal economies of PICTs are matched by the role fisheries and aquaculture play in helping to provide good nutrition and livelihoods across the region {Chapter 12}. Fish[i] is a cornerstone of food security for the people of the tropical Pacific – fish provide 50–90% of animal protein in the diet of coastal communities across a broad spectrum of PICTs, and national fish consumption per person in many PICTs is more than 3–4 times the global average[2]. In rural areas, much of this fish (60–90%) is caught by subsistence fishing. Many people in the Pacific also catch and sell fish – an average of 47% of households in representative coastal communities in 17 PICTs derive either their first or second income in this way[3]. Industrial fishing and processing operations provide more than 12,000 jobs[1], and aquaculture employs more than 6000 people in pearl and shrimp farming and supplies another 10,000 households with fish to eat or sell[4] {Chapter 11}.

As a consequence of such benefits, the Pacific Plan[5] recognises that development of PICTs is linked to the effective management of fish, and the habitats that support them – 'd*evelopment and implementation of national and regional conservation and management measures for the sustainable use of fisheries resources'* is a priority of the Plan. Responsible and effective stewardship of the region's fisheries resources has also been reinforced by the Pacific Island Forum Leaders' 'Vava'u Declaration'[ii]. The recent 'Future of Pacific Island Fisheries' study[6] outlines the various drivers affecting the sector, and the actions that need to be taken to optimise the economic and social benefits of fisheries and aquaculture for PICTs.

Climatic variation, which is known to have profound effects on the distribution and abundance of fish and the productivity of aquaculture both in the tropical Pacific {Chapters 8–11} and elsewhere in the world {Chapter 1}, is expected to grow in importance as a driver of the sector. Pacific Island countries and territories need to know whether future changes in climate and acidification of the ocean are likely to derail the plans being developed to optimise the great economic and social benefits they receive from fisheries and aquaculture.

To answer this important question, the Secretariat of the Pacific Community (SPC) coordinated a comprehensive assessment of the vulnerability of tropical Pacific fisheries and aquaculture to climate change[7]. The assessment included the full range

i Fish is used in the broad sense to represent both fish and invertebrates.

ii www.forumsec.org.fj/pages.cfm/documents/forum-resolutions of oceanic, coastal and freshwater fisheries, and aquaculture activities, that occur in PICTs and spanned the area from 130°E to 130°W and 25°N to 25°S. The assessment was based on the analyses described below.

- Observed and projected changes to surface climate and the tropical Pacific Ocean.
- Effects of changes to the surface climate and ocean on the marine and freshwater ecosystems (fish habitats) that support fisheries and aquaculture in the region.
- Direct effects of changes to surface climate and the ocean, and the indirect effects of changes to fish habitats, on the distribution and abundances of the fish and invertebrate stocks underpinning oceanic, coastal and freshwater fisheries and aquaculture in the tropical Pacific.
- Implications of climate change for contributions by fisheries and aquaculture to the economic development and government revenue of PICTs, and the food security and livelihoods of their people.
- Adaptations and suggested policies to minimise the threats and capitalise on the opportunities expected to occur as a result of the changing climate.
- Gaps in knowledge that need to be filled to improve confidence in assessments of vulnerability and the research needed to provide this information.
- Investments required to launch priority adaptations and fill gaps in knowledge.

The vulnerability assessments for natural resources, economies, food security and livelihoods were made for representative low (B1) and high (A2) emissions scenarios from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR4)[8] for two future timeframes, 2035 and 2100. Under the B1 scenario, the concentration of carbon dioxide (CO_2) in the atmosphere is projected to reach 400–450 ppm by 2035, and 500–600 ppm by 2100. Concentrations of CO_2 are also projected to be 400–450 ppm by 2035 under the A2 scenario, but increase to 750–800 ppm under A2 by 2100[9] {Chapter 1}[10].

Because global CO_2 emissions currently exceed those projected by the A2 emissions scenario[iii], and because PICTs are also interested in their vulnerability in the near to mid term, we also assessed the implications of climate change for contributions by fisheries and aquaculture to economies and communities for the A2 scenario in 2050[iv].

The vulnerabilities of fish habitats and stocks, and the economic and social benefits of fisheries and aquaculture, were based on the widely accepted framework adopted by the IPCC, and several other initiatives aimed at assessing vulnerability to climate change (Figure 1.1) {Chapter 1}. The framework assesses vulnerability as a function of exposure, sensitivity and adaptive capacity.

iii See www.esrl.noaa. gov/gmd/ccgg/trends/#mlo_growth for the latest trends in the growth of CO_2 emissions.

iv Projections for the A2 emissions scenario in 2050 were made by using model outputs for the B1 emissions scenario in 2100 as a surrogate for A2 in 2050 {Chapter 1}.

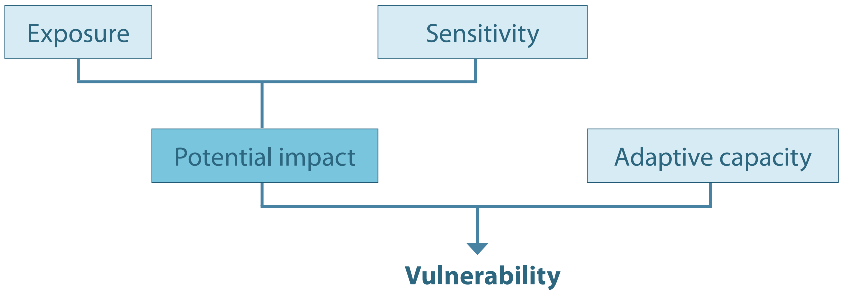


Figure 1.1 Framework used to assess the vulnerability of fisheries and aquaculture in the tropical Pacific to climate change. Adapted from Schroter and ATEAM Consortium (2004)[23].

Using this framework, the projected changes in atmospheric (surface climate) and oceanic conditions under the four combinations of emissions scenarios (B1 and A2) and timeframes (2035 and 2100) (hereafter referred to simply as four scenarios)[v] were cascaded along two pathways (Figure 1.2). In one pathway, the projected changes to surface climate {Chapter 2}[11] and the tropical Pacific Ocean {Chapter 3}[12] were used to define the 'direct' exposure of fish stocks supporting fisheries and aquaculture to climate change and ocean acidification. In a second pathway, the vulnerability assessments for the ecosystems underpinning fisheries and aquaculture {Chapters 4–7}[13–16] were used to determine the 'indirect' exposure of fish stocks. Estimates of the direct and indirect exposure of stocks were then integrated to make separate vulnerability assessments for oceanic, coastal and freshwater fisheries, and aquaculture, under each of the four scenarios defined above {Chapters 8–11}[17–20]. Next, the projected changes to fish stocks and aquaculture production were used to identify (1) the threats posed by climate change to plans to optimise the sustainable benefits from fisheries and aquaculture for economic development, government revenue, food security and livelihoods; and (2) opportunities to enhance these plans {Chapter 12}[21].

The final step in the assessment was to recommend practical adaptations and suggested supporting policies to reduce the threats and capitalise on the opportunities. These adaptations and policies are not limited to dealing with the projected effects of a changing climate, however. Wherever possible, 'win-win' solutions have been identified that address the effects of (1) other factors affecting the benefits derived from fisheries and aquaculture production in the near term (e.g. population growth); and (2) climate change in the long term {Chapter 13}[22].

v Note that due to the similar projections for CO_2 emissions under the B1 and A2 scenarios in 2035, they have usually been considered together throughout this summary.

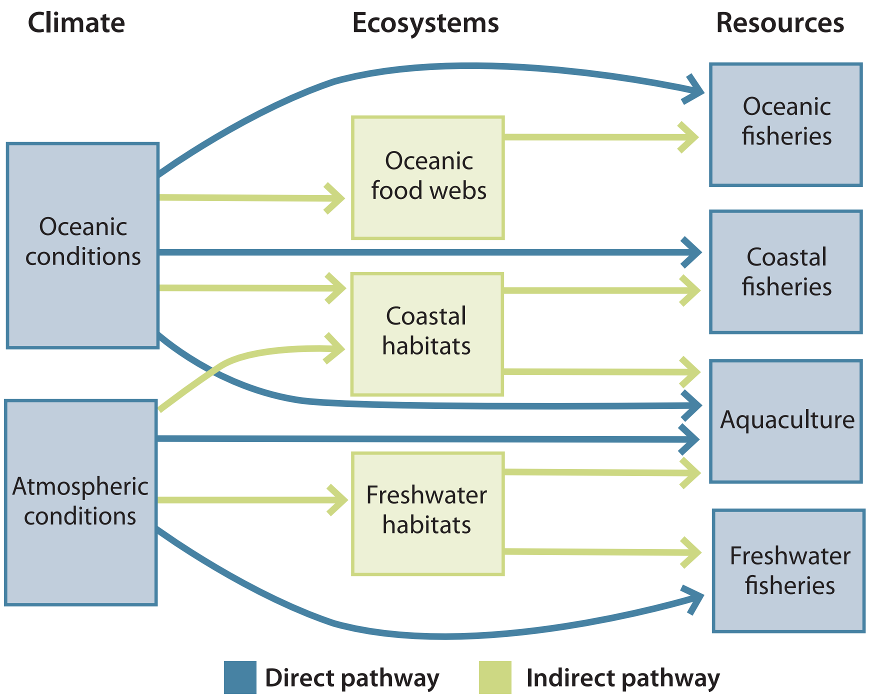


Figure 1.2 The two pathways used to develop scenarios for the exposure of the various fisheries resources and aquaculture in the tropical Pacific to climate change.

This 'Summary for Pacific Island countries and territories' has been designed to present the key findings of the vulnerability assessment in a way that is useful for all stakeholders in the fisheries and aquaculture sector.

Section 2 summarises the following key information for each PICT:

- The existing features of surface climate and tropical Pacific Ocean in the vicinity of the country or territory, and the projected changes to surface climate and the ocean under the B1 and A2 emissions scenarios in 2035 and 2100.
- The importance of oceanic fisheries, coastal fisheries, freshwater and estuarine fisheries (if appropriate) and aquaculture to the country or territory. For each resource, this information includes the value and volume of recent production, the extent of the habitats supporting production, projected alterations to these habitats under climate change, and the projected changes to fish catches or aquaculture production due to the direct and indirect effects of climate change.
- The present contributions of fisheries and aquaculture to economic development and government revenue, food security and livelihoods, and the implications of climate change for these economic and social benefits.

- Recommended adaptations and suggested supporting policies to (1) reduce the threats of climate change to the future contributions by fisheries and aquaculture to economic development and government revenue, food security and livelihoods; and (2) capitalise on any opportunities.

In the interests of keeping the summary for each PICT short, the adaptations and policies are described only briefly in **Section 2** and links are provided to the detailed descriptions of adaptations and suggested policies in **Section 3**.

Section 4 outlines the gaps in knowledge that remain to be filled to enable the region to assess the vulnerability of fisheries and aquaculture to climate change with more confidence. This section also summarises the research needed to fill the gaps.

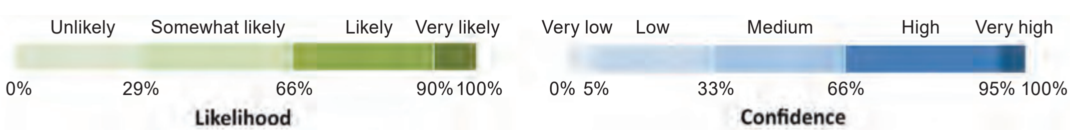
Section 5 summarises the investments required to launch the adaptations recommended for the fisheries and aquaculture sector across the region, and progressively fill the gaps in knowledge.

Section 6 provides brief descriptions of the modelling done to produce this vulnerability assessment {Chapter 1} and the main projected changes to surface climate {Chapter 2}, the tropical Pacific Ocean {Chapter 3}, fish habitats {Chapters 4–7}, fish stocks {Chapters 8–10} and aquaculture {Chapter 11}. As shown in Figure 1.2, this information has been cascaded throughout the assessment to identify (1) the implications of climate change for the contributions of fisheries and aquaculture to economic development and government revenue, food security and livelihood opportunities for PICTs; and (2) the appropriate adaptations and supporting policies.

Sections 6.2 and **6.3** contain information on surface climate and the tropical Pacific Ocean essential for interpreting the summaries for each country and territory, and should be read before proceeding to **Section 2**.

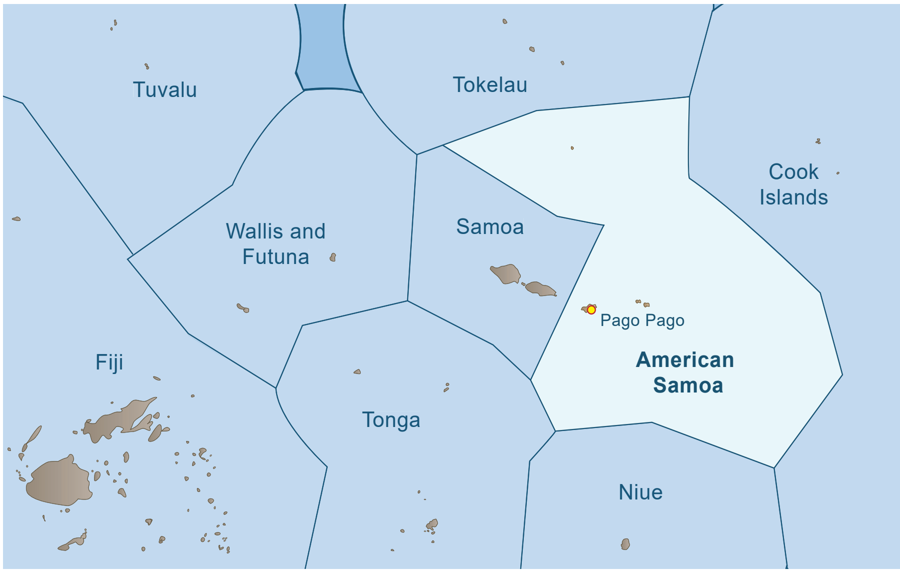
Throughout this summary, cross references to the relevant chapters of the full vulnerability assessment[7] have been provided in curly brackets – { } – so that readers can find the details of the analyses on which the conclusions have been based. Cross references to other parts of the summary are also provided in normal brackets. Other references have been kept to a minimum and listed at the end of this volume.

Likelihood and confidence values have been attributed to the projected effects of climate change on surface climate, the ocean, fish habitats, fisheries and aquaculture in the summaries for each country and territory using the key below.



2. Summaries for each country and territory

2.1 American Samoa



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	66	87	98	135
Population growth rate[a]	1.2	1.0	0.8	0.5

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 434,503

Land area (km²) 197

Land as % of EEZ 0.045

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries, with some limited freshwater and estuarine fisheries and freshwater pond aquaculture.

Membership of regional fisheries management arrangements: Western Pacific Regional Fisheries Management Council; Western and Central Pacific Fisheries Commission (participating territory).

Surface climate and the ocean

Existing features

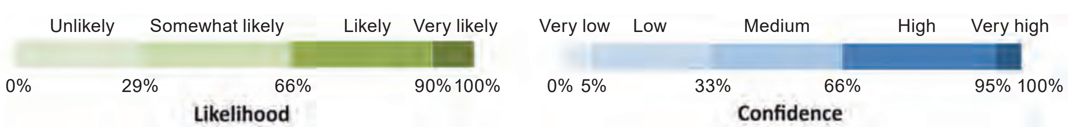
American Samoa has a tropical climate {Chapter 2}. Recent air temperatures in Pago Pago have averaged 27.4°C and average rainfall is ~ 3100 mm per year. American Samoa lies within the South Pacific Subtropical Gyre Province (SPSG) {Chapter 4, Figure 4.6}. The SPSG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}.

Projected changes to surface climate

Air temperatures and rainfall in American Samoa are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.4 (Pago Pago)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	3088 (Pago Pago)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	n/a	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of American Samoa, see www.cawcr.gov.au/projects/PCCSP; n/a = data not available.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding American Samoa relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	28.5[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

The national industrial fleet targets albacore, with an annual catch of > 4600 tonnes, worth > USD 23.7 million. American Samoa also licenses foreign vessels to fish for tuna within its exclusive economic zone (EEZ), although recent annual catches (2004–2008) have been < 50 tonnes. In contrast, an average of ~ 107,600 and ~ 10,300 tonnes of tuna have been landed in American Samoa by foreign purse-seine and longline fleets, respectively, in recent years. These landings demonstrate the importance of fish processing operations in American Samoa to the region. See 'Coastal Fisheries' below for contributions of tuna to nearshore small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Longline	4577	23.7
Other methods	11	0.03
Other oceanic fish[a]	39	0.04
Total	**4627**	**23.77**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

American Samoa's EEZ lies within the generally nutrient-poor waters of the SPSG Province {Chapter 4, Figure 4.6}. This province is characterised by downwelling and low nitrate concentrations in deeper waters. Net primary production is low, particularly in summer when there is the formation of a marked thermocline {Chapter 4, Section 4.4.3}. Local upwelling around islands can result in small areas of enriched surface productivity. In general, however, the SPSG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the SPSG Province is projected to increase and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease slightly in SPSG {Chapter 4, Table 4.3}.

SPSG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+4	+7	+7	+14
Location	Poleward extension of southern limit			
Net primary production	-3	-5	-3	-6
Zooplankton biomass	-3	-4	-5	-10

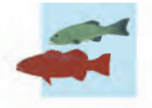
* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of American Samoa are expected to increase significantly in 2035 and 2100, relative to the 20-year average (1980–2000). However, catches of bigeye tuna are projected to decrease under both scenarios in 2035 and 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward and to be more abundant at the edges of the SPSG Province.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+41	+48	+58	-5	-8	-18

* Approximates A2 in 2050.



Coastal fisheries

Recent catch and value

The coastal fisheries of American Samoa are made up mainly of three components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 155 tonnes in 2007, worth USD 644,000. The commercial catch was 35 tonnes. Demersal fish are estimated to make up 60% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	92	47	0	16	155	0.64
Contribution (%)[a]	60	30	0	10	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

American Samoa has relatively small areas of coral reef habitat {Chapter 5}. Mangroves, seagrasses and intertidal flats make up limited, and often unknown, areas of the coastal zone {Chapter 6}.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	368	0.5	n/a	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs and mangroves (and any seagrasses and intertidal flats) in American Samoa, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area[c]	-10	-50	-60
Seagrass area[c]	-5 to -20	-5 to -35	-10 to -50

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs; c = indicative estimates from Samoa {Chapter 6}.

Projected changes in coastal fisheries production

Fisheries for demersal fish and intertidal and subtidal invertebrates in American Samoa are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna contribute to the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relatively heavy reliance on demersal fish, offset to some extent by the projected increase in productivity of the nearshore pelagic component of the fishery. As a result, total catches from coastal fisheries in American Samoa are projected to increase slightly under both scenarios in 2035 but decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	60	-3.5	-2	-20	-12	-35	-21
Nearshore pelagic fish	30	+17.5	+5	+20	+6	+10	+3
Inter/subtidal invertebrates	10	0	0	-5	-0.5	-10	-1
Total catch[a]			**+3**		**-6.5**		**-19**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in American Samoa; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in American Samoa are flagtails (jungle perch), eels, gobies and *Macrobrachium*. These species are taken mostly by subsistence fisheries as food from lowland rivers. The estimated annual freshwater fish catch in 2007 was 1 tonne, worth USD 4000 {Chapter 10}[1].

Existing freshwater and estuarine fish habitat

The largest river in American Samoa, Laufuti, is only 3 km in length and supports a limited range of freshwater and estuarine fish habitats {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km^2)	River length (km)
Ta'u	Laufuti	8	3

Projected changes to freshwater and estuarine fish habitat

The projected increase in rainfall for American Samoa {Chapter 2, Section 2.5.2} is expected to result in modest increases in the area and quality of freshwater fish habitats {Chapter 7, Table 7.5}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	B1 2100*	A2 2100
-5 to +5	-5 to +5	-5 to +10

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Higher projected rainfall and river flows are expected to result in slightly improved production from freshwater and estuarine fisheries in American Samoa. River flow increases the availability and quality of habitats, provides cues for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
0	0	+2.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

The main aquaculture commodity in American Samoa is tilapia, grown in freshwater ponds for local consumption. In 2007, the total production of tilapia was estimated to be 9 tonnes, worth USD 10,000[1]. Most of the future aquaculture potential is expected to be based on increased development of fish farming in freshwater ponds.

Existing and projected environmental features

Higher rainfall and air temperatures are expected to improve conditions for growing tilapia in freshwater ponds in American Samoa {Chapter 11}.

Environmental feature	1980–1999 average[a]	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.4	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	3088	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%

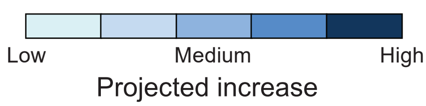
* Approximates A2 in 2050; a = data for Pago Pago.

Projected changes in aquaculture production

The projected effects of climate change on pond aquaculture in American Samoa are expected to be positive. Production of tilapia is likely to be enhanced due to increased rainfall, river flows and temperatures, provided ponds are located where they will not be affected by floods or storm surge {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Tilapia	Food security			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

Tuna canning operations have contributed > 20% to the gross domestic product (GDP) of American Samoa in recent years {Chapter 12}. The industrial longline tuna fishery also contributed 0.6% to GDP in 2007 but does not provide any government revenue (GR) {Chapter 12}.

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Longline	2.8	0.6	0	0

* Information for 2007, when national GDP was USD 462 million (Gillett 2009)[1]; ** information for 2003, when total GR was USD 155 million.

Projected effects of climate change

The projected changes to GDP derived from longline fishing operations due to the effects of climate change on the distribution and abundance of tuna are difficult to estimate for American Samoa because modelling has yet to be done for albacore. However, the projected increases in skipjack tuna catch across the region in 2035 and 2050 {Chapter 8}, should facilitate delivery of fish for canning operations and increase the potential contributions of canneries to GDP in the near to medium term.

Projected changes to GDP (%)**			Projected changes to GR (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+3 to +6	+2 to +4	-1 to -2	n/a	n/a	n/a

* Approximates A2 in 2050; ** based on canning operations; n/a = not applicable because no government revenue is earned from tuna fishing.

Food security

American Samoa is among the group of PICTs (Group 3) where the estimated sustainable production of fish and invertebrates from coastal habitats is unable to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}. However, rural communities on the outer islands consume > 60 kg of fish per person per year {Chapter 12, Table 12.5}.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Current contributions of fish to food security

At present, coral reefs in American Samoa are estimated to be able to supply the national population with only 17 kg of fish per person per year, a significant shortfall below the recommended consumption. In support of this assessment, estimates of total coastal (commercial and subsistence) fish production in 2007 were 15.5 kg per person[1].

Effects of population growth

The existing gap between the fish estimated to be available from coastal habitats, and the fish recommended for good nutrition, is 18 kg per person per year. This gap is expected to increase progressively due to the effects of population growth, reaching 27 kg per person by 2100.

Variable	2010	2035	2050	2100
Population (x 1000)	66	87	98	135
Fish available per person (kg/year)[a]	17	13	11	8
Gap (kg/person/year)[b]	18	22	24	27

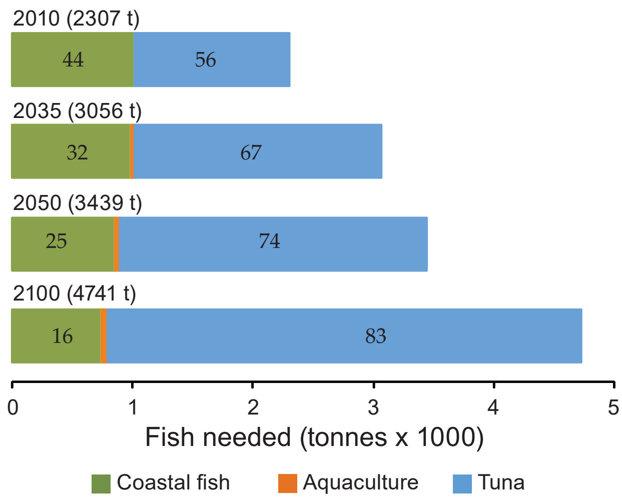
a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The effects of climate change on coastal fisheries are likely to cause only relatively minor additional declines in the fish available per person. Under the A2 emissions scenario, the direct and indirect effects of climate change on coastal fisheries are expected to increase the gap from 24 to 25 kg per person per year by 2050, and from 27 to 29 kg in 2100.

Filling the gap

Fresh tuna caught within American Samoa's EEZ, or canned tuna produced in the nation's canneries, is the main resource available to help provide access to the fish needed to overcome the shortfall in supplies from coastal habitats. At present, access to at least another 2300 tonnes of fish is needed nationally to provide the 35 kg per person per year recommended for good nutrition. Tuna has to meet > 50% of all fish required for food. The quantities of fish needed for good nutrition more than double by the end of the century. The proportions of tuna required to fill the gap also increase over time, reaching 67% in 2035, 74% in 2050, and 83% by 2100. The implication is that greater quantities of tuna from national catches will need to be allocated for food security.



Fish (in tonnes) needed for future food security in American Samoa, and the recommended contributions (%) of fisheries resources and aquaculture production required to meet future needs.

Livelihoods

Current contributions

Large numbers of full-time and part-time jobs have been created through tuna processing in American Samoa {Chapter 12}. Similar numbers of people have been employed indirectly by government and the private sector as a result of fish processing operations[1].

Jobs on tuna vessels*	Jobs in shore-based tuna processing*	Jobs in aquaculture**
n/a	4757[a]	15

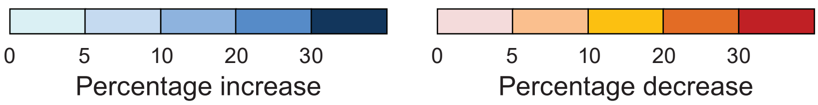
* Information is for 2006 derived from Chapter 12, Table 12.6; ** information is for 2007 from Ponia (2010)[4]; a = note that there are now fewer jobs due to closure of one of the canneries in American Samoa; n/a = no data available.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and pond aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario			
	Oceanic fisheries**	Coastal fisheries		Aquaculture
		Nearshore pelagic fish	Other resources	(ponds)
Present*	⇧	⇧	⇩	⇧
2035	↑	↑	↓	↑
2050	↑	↑	↓	↑
2100	↑	↑	↓	↑

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due to their subsistence role.



Adaptations and suggested policies

The plans American Samoa has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. secure continued access to the tuna required by canneries;
2. increase access to tuna to provide the fish needed for food security for both rural and urban communities; and
3. increase the number of livelihoods that can be based on fishing and processing tuna, and on pond aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E2	Diversify sources of fish for canneries	E1–E5
E3	Immediate conservation management measures for bigeye tuna	E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E6	Gender-sensitive fish processing operations	
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

Food security

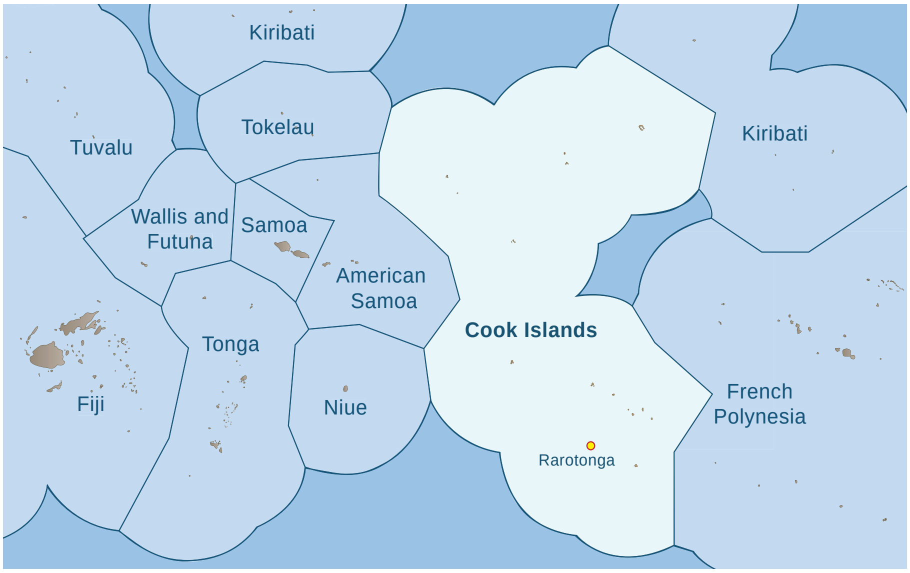
Adaptation no. (Section 3.4)*	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	F13–16, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

* Adaptations for freshwater habitats and fish stocks not included due to the limited nature of these resources but see adaptations F4 and F7 (Section 3.4), and policies F4, F6, F13 and F18 (Section 3.5).

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L3	Develop coral reef ecotourism ventures	L3

2.2 Cook Islands



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	16	17	16	16
Population growth rate[a]	0.3	0	-0.2	0

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 1,947,760

Land area (km²) 240

Land as % of EEZ 0.012

Fisheries and aquaculture activities: Oceanic fisheries, coastal fisheries, coastal aquaculture with some limited freshwater and estuarine fisheries and freshwater pond aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Te Vaka Moana Arrangement; South Pacific Regional Fisheries Management Organisation; South Pacific Tuna and Billfish subcommittee.

Surface climate and the ocean

Existing features

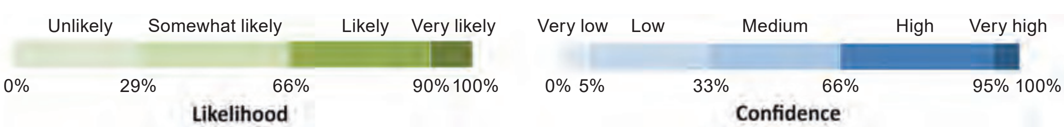
Cook Islands has a mainly tropical climate {Chapter 2}. Recent air temperatures in Rarotonga have averaged 24.4°C and average rainfall is ~ 1800 mm per year. Cook Islands lies within the South Pacific Subtropical Gyre Province (SPSG) {Chapter 4, Figure 4.6}. The SPSG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}.

Projected changes to surface climate

Air temperatures and rainfall in Cook Islands are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	24.4 (Rarotonga)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1802 (Rarotonga)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	0.7 to 1.2	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Cook Islands, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Cook Islands relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	26.5[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

Recent average annual catches (2004–2008) from the local longline fleet exceed 3600 tonnes, worth > USD 17 million. The local fleet mainly targets yellowfin tuna, bigeye tuna and albacore. Foreign vessels under charter also made annual average catches of 650 tonnes of tuna from the exclusive economic zone (EEZ) of Cook Islands between 1999 and 2008. See 'Coastal Fisheries' below for contributions of tuna to nearshore small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Longline	3300	16.8
Other methods	128	0.3
Other oceanic fish[a]	189	0.2
Total	**3617**	**17.3**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

Cook Island's EEZ lies within the generally nutrient-poor waters of the SPSG Province {Chapter 4, Figure 4.6}. This province is characterised by downwelling and low nitrate concentrations in deeper waters. Net primary production is low, particularly in summer when there is the formation of a marked thermocline {Chapter 4, Section 4.4.3}. Local upwelling around islands can result in small areas of enriched surface productivity. In general, however, the SPSG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the SPSG Province is projected to increase and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease slightly in SPSG {Chapter 4, Table 4.3}.

SPSG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+4	+7	+7	+14
Location	Poleward extension of southern limit			
Net primary production	-3	-5	-3	-6
Zooplankton biomass	-3	-4	-5	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Cook Islands are expected to increase significantly in 2035 and 2100, relative to the 20-year average (1980–2000). However, catches of bigeye tuna are projected to decrease under both scenarios in 2035 and 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward and to be more abundant at the edges of the SPSG Province.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+40	+50	+47	-3	-8	-15

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Cook Islands are made up mainly of three components: demersal fish (bottom-dwelling fish associated with coral reef habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. Invertebrates targeted for export (trochus) contribute to the catch in some years. The total annual catch was estimated to be 400 tonnes in 2007, worth > USD 2.3 million. The commercial catch was 133 tonnes. Nearshore pelagic fish are estimated to make up 60% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	146	240	0	14	400	2.3
Contribution (%)[a]	37	60	0	3	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

The area of coral reef habitat supporting coastal fisheries in Cook Islands is 667 km^2 {Chapter 5}. Mangroves, and most probably seagrasses, do not occur in Cook Islands. Intertidal flats do occur around the interior of atoll lagoons but the areas of these habitats have not been reported {Chapter 6}.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	667	0	0	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs in Cook Islands, resulting in projected declines in percentage coral cover in both the medium and long term {Chapter 5}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish and intertidal and subtidal invertebrates in Cook Islands are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relatively heavy reliance on nearshore pelagic fish. As a result, potential catches from coastal fisheries in Cook Islands are projected to increase under both scenarios in 2035 and B1 in 2100, but eventually decline under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	37	-3.5	-1.3	-20	-7.4	-35	-13
Nearshore pelagic fish	60	+17.5	+10.5	+20	+12	+10	+6
Inter/subtidal invertebrates	3	0	0	-5	-0.2	-10	-0.4
Total catch[a]			**+9**		**+4**		**-7**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Cook Islands; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in Cook Islands include eels, tilapia and *Macrobrachium*. The estimated annual freshwater fish catch in 2007 was ~ 5 tonnes, worth > USD 35,000 {Chapter 10}[1].

Existing freshwater and estuarine fish habitat

The relatively small rivers and lakes of Cook Islands provide only a limited range of freshwater and estuarine fish habitats, but support several fish and invertebrate species. The longest river is the Avatiu on Rarotonga {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km²)	River length (km)
Rarotonga	Avatiu	5.5	5

Projected changes to freshwater and estuarine fish habitat

The projected increase in rainfall for Cook Islands {Chapter 2, Section 2.5.2} is expected to result in increases in the area and quality of freshwater fish habitats {Chapter 7, Table 7.5}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	B1 2100*	A2 2100
-5 to +10	-5 to +10	-5 to + > +20

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Higher projected rainfall and river flows are expected to result in slightly improved production from freshwater and estuarine fisheries in Cook Islands. River flow increases the availability and quality of habitats, provides cues for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
+2.5	+2.5	+7.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

The main aquaculture commodity in Cook Islands is black pearls. Other commodities produced from coastal waters include marine ornamentals (giant clams), juvenile wild milkfish, which are stocked in natural ponds on some atolls. There is also interest in evaluating the grow-out of wild-caught juvenile milkfish for tuna bait in Penrhyn Atoll, and farming *Macrobrachium* and tilapia in freshwater ponds.

Existing and projected environmental features

Higher rainfall and air temperatures are expected to have positive effects on pond aquaculture. However, increasing SST, rainfall and ocean acidification, and possibly more severe cyclones, are expected to reduce the survival and growth of pearl oyster spat and ornamental products. Acidification of the ocean may also affect the formation of nacre by pearl oysters, and therefore pearl quality {Chapter 11}.

Environmental feature	**1980–1999 average**	**Projected change**			
		B1 2035	**A2 2035**	**B1 2100***	**A2 2100**
Air temperature (°C)	24.4[a]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	1802[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Cyclones (no. per year)	0.7 to 1.2	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	26.5	+5 to +15%	+5 to +15%	+5 to +15%	+5 to +15%
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

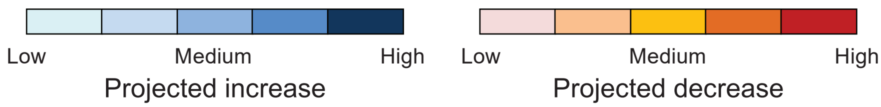
* Approximates A2 in 2050; a = data for Rarotonga.

Projected changes in aquaculture production

The projected effects of climate change on aquaculture are mixed. Pond aquaculture is expected to be enhanced by increased rainfall, river flows, and warmer temperatures, provided ponds are located where they will not be affected by floods or storm surge. The commodities grown in coastal waters are likely to be affected adversely by increases in SST, rainfall, ocean acidification and stronger storm surge from more severe cyclones {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Existing				
Pearls	Livelihoods	↓	↓	↓
Marine ornamentals	Livelihoods	↓	↓	↓
Milkfish	Food security	↑	↑	↑
Potential				
Tilapia	Food security	↑	↑	↑
Macrobrachium	Livelihoods	↑	↓	↓

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The industrial tuna longline fishery contributes only 0.1% to gross domestic product (GDP) in Cook Islands. Licence fees from foreign vessels engaged in the longline and surface fisheries for tuna are more important – they contributed 1.4% and ~ 0.3% to government revenue (GR), respectively, in 2007 {Chapter 12} and revenues have increased since then.

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Surface	0	0	0.26	0.3
Longline	0.2	0.1	1	1.4

* Information for 2007, when national GDP was USD 211 million (Gillett 2009)[1]; ** information for 2003, when total GR was USD 86 million.

Projected effects of climate change

Although catches of tuna in the EEZ of Cook Islands are projected to increase by 40–50% due to climate change, the effects of increased catches on GDP and GR are expected to be minor due to the small contributions of oceanic fisheries to the economy.

Food security

Cook Islands is among the group of PICTs (Group 1) where the estimated sustainable production of fish and invertebrates from coastal habitats will be more than enough to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Cook Islands is estimated to be 35 kg per person per year[2], matching the recommended level for good nutrition. Consumption is higher in rural areas, where it averages > 60 kg per person per year. At present, coral reefs in Cook Islands are estimated to be able to supply ~ 130 kg of demersal fish per person per year, although ciguatera fish poisoning prevents many species from being used for food in some locations {Chapter 9}. Rarotonga depends on fish from elsewhere to meet the demand of the local population and tourism.

Fish consumption per person (kg)			Animal protein from fish (%)		Fish provided by subsistence catch (%)	
National	Rural	Urban	Rural	Urban	Rural	Urban
35	61	25	51	27	76	27

Effects of population growth

The population of Cook Islands is predicted to remain stable over this century, and coastal fisheries are expected to continue to produce fish surplus to the demand for food {Chapter 12}.

Variable	2010	2035	2050	2100
Population (x 1000)	16	17	16	16
Fish available per person (kg/year)[a]	128	119	119	125
Surplus (kg/person/year)[b]	93	84	84	90

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The effects of climate change on coastal fisheries are likely to cause only minor reductions in the significant surplus of fish available for food. Even with the projected decreases in production of demersal fish of up to 50% by 2100 under the A2 emissions scenario, the large area of coral reef relative to population size should continue to

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

supply sufficient coastal fish for food security {Chapter 12, Table 12.10}. Projected increases in tuna catch by the nearshore fishery are expected to further increase access to fish.

Livelihoods

Current contributions

Pearl farming provides the greatest number of jobs for the sector, with up to 450 people being employed in recent years {Chapter 12}. In contrast, full-time and part-time jobs created through tuna fishing and processing represent only a low percentage of total employment. Coastal fisheries also provide important opportunities to earn income for coastal communities, with 20% of households deriving their first or second incomes by catching and selling fish.

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
50	15	12	15	15	10	12	8	20	450

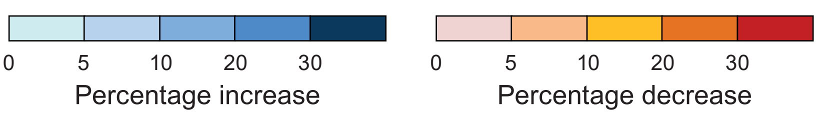
* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and pond aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario				
	Oceanic fisheries**	Coastal fisheries		Aquaculture	
		Nearshore pelagic fish	Other resources	Ponds	Coastal
Present*	⇧	⇧	⇩	⇧	⇧
2035	↑	↑	↓	↑	↓
2050	↑	↑	↓	↑	↓
2100	↑	↑	↓	↑	↓

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due to their subsistence role.



Adaptations and suggested policies

The plans Cook Islands has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. improve access to tuna, and the efficiency of local industrial fishing operations, to increase the contributions from oceanic fisheries resources to economic development;
2. manage coastal fish habitats and fish stocks to ensure that they continue to provide fish for food security; and
3. increase the number of livelihoods that can be based on fishing, tourism and aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E1	Full implementation of sustainable fishing effort schemes	E1, E2, E4–E6
E3	Immediate conservation management measures for bigeye tuna	E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

Food security

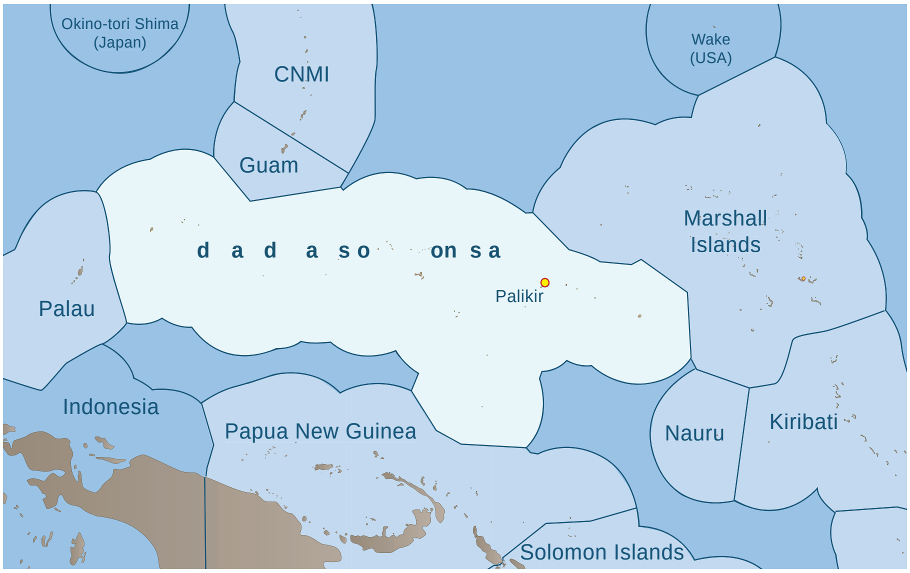
Adaptation no. (Section 3.4)*	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F8	Increase access to tuna for urban and rural populations	F8–F13, F18

* Adaptations for freshwater habitats and fish stocks not included due to the limited nature of these resources but see adaptations F4 and F7 (Section 3.4), and policies F4, F6, F13 and F18 (Section 3.5).

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.3 Federated States of Micronesia



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	102	105	109	109
Population growth rate[a]	-0.4	0.4	0.1	0

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 2,939,300

Land area (km²) 700

Land as % of EEZ 0.024

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries, with some limited freshwater and estuarine fisheries and coastal aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Parties to the Nauru Agreement.

Surface climate and the ocean

Existing features

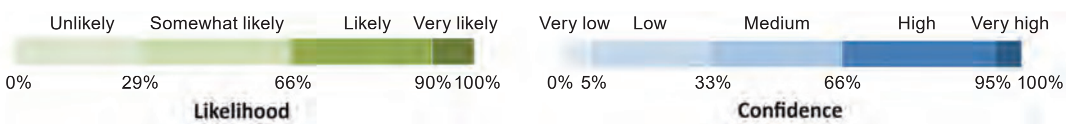
Federated States of Micronesia (FSM) has a tropical climate {Chapter 2}. Recent air temperatures in Pohnpei have averaged 27.3°C and average rainfall is ~ 4600 mm per year. FSM lies mainly within the Western Pacific Warm Pool Province (Warm Pool) {Chapter 4, Figure 4.6}. The primary influence on surface climate in the Warm Pool is the El Niño-Southern Oscillation (ENSO), which also affects the surrounding ocean. Under normal conditions the net primary production (NPP) in this part of the ocean is low due to the deep thermocline. However, NPP increases during El-Niño episodes because the thermocline becomes shallower.

Projected changes to surface climate

Air temperatures and rainfall in FSM are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.3 (Pohnpei)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	4588 (Pohnpei)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			

* Approximates A2 in 2050; a = for more detailed projections of rainfall and air temperature in the vicinity of FSM, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding FSM relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the North Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	29.1[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in North Pacific gyre	Continued increase in strength of North Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

The local industrial surface fishery for tuna operates inside and outside the exclusive economic zone (EEZ) of FSM. Average annual catches by this fishery are 19,500 tonnes per year, worth > USD 23 million. The locally-based longline fishery catches > 900 tonnes of tuna per year, worth ~ USD 5 million. FSM also licenses foreign purse-seine vessels to fish for tuna within its EEZ. Between 1999 and 2008, these foreign vessels made an average total annual catch of > 152,000 tonnes, worth USD 126 million. Foreign longline fleets also landed average catches of > 5500 tonnes, worth USD 26 million. Significant quantities of tuna are also landed in FSM for transhipping to canneries in Asia {Chapter 12}. See 'Coastal Fisheries' below for contributions of tuna to nearshore small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Purse-seine	19,544	23.1
Longline	938	4.9
Other oceanic fish[a]	136	0.1
Total	**20,618**	**28.1**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The Warm Pool is generally poor in nutrients, although net primary production increases during El Niño events, when the depth of the thermocline decreases, bringing more nutrient-rich waters within the photic zone {Chapter 4, Section 4.3.2}. The convergence between the Warm Pool and the Pacific Equatorial Divergence (PEQD) provinces creates prime feeding areas for tuna {Chapters 4 and 8}. The westward contraction of the Warm Pool during La Niña episodes increases the abundance of tuna near the EEZ of FSM.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the Warm Pool is projected to expand {Chapter 4, Table 4.3}. The greater stratification of the water column in the Warm Pool due to higher sea surface temperature {Chapter 3}, and the increased depth of the nutricline {Chapter 4}, are projected to reduce net primary production within the EEZ of FSM. Relocation of the convergence zone between the Warm Pool and PEQD to the east is also expected to increase the distance between FSM's EEZ and the prime feeding grounds for tuna {Chapter 8}.

Warm Pool feature	**Projected change (%)**			
	B1 2035	**A2 2035**	**B1 2100***	**A2 2100**
Surface area[a]	+18	+21	+26	+48
Location	Eastwards			
Net primary production	-7	-5	-9	-9
Zooplankton biomass	-6	-3	-9	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of FSM are expected to increase by 14% in 2035, relative to the 20-year average (1980–2000). However, by 2100 under the B1 scenario (A2 in 2050), the increase in skipjack tuna catch is only likely to be small, and is expected to decrease considerably under A2 in 2100. Catches of bigeye tuna are projected to decrease under both scenarios in 2035 and 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+14	+5	-16	-3	-11	-32

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of FSM are made up of four categories: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 12,600 tonnes in 2007, worth > USD 23.0 million. The commercial catch was 2800 tonnes. Demersal fish are estimated to make up 50% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	6290	3560	30	2720	12,600	23.3
Contribution (%)[a]	50	28	< 1	22	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch currently comprised equally of tuna and non-tuna species.

Existing coastal fish habitat

FSM has very significant areas (> 15,000 km^2) of coral reef, as well as mangroves and seagrasses that support many coastal fisheries species {Chapters 5 and 6}. The areas of intertidal sand and mud flats have not been measured.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	15,074	86	44	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in FSM, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	< -5 to -10	-5 to -25	-10 to -30

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

All components of coastal fisheries in FSM are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna contribute to the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the expected decrease in the productivity of all coastal fisheries categories. As a result, total catches from coastal fisheries in FSM are projected to decrease slightly under both scenarios in 2035, and to decline substantially under both scenarios in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	50	-3.5	-2	-20	-10	-35	-17.5
Nearshore pelagic fish	28	0	0	-10	-3	-17.5	-5
Targeted invertebrates	< 1	-3.5	-0.007	-10	-0.2	-20	-0.4
Inter/subtidal invertebrates	22	0	0	-5	-1	-10	-2
Total catch[a]			**-2**		**-14**		**-25**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in FSM; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in FSM are eels, tilapia and *Macrobrachium*. These species are mostly taken by subsistence fishing from rivers and lakes. The estimated annual freshwater fish catch in 2007 was 1 tonne, worth USD 8000 {Chapter 10}.

Existing freshwater and estuarine fish habitat

The largest river in FSM, Nanpil Kiepw, is only 10 km in length and has a limited range of freshwater and estuarine fish habitats {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km^2)	River length (km)
Pohnpei	Nanpil Kiepw	7.8	10

Projected changes to freshwater and estuarine fish habitat

The projected increase in rainfall for FSM {Chapter 2, Section 2.5.2} is expected to result in increases in the area and quality of freshwater fish habitats {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	B1 2100*	A2 2100
-5 to +5	-5 to +10	-5 to +20

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Higher projected rainfall and river flows are expected to result in slightly improved production from freshwater and estuarine fisheries in FSM. River flow increases the availability and quality of habitats, provides cues for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
0	0	+7.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

The main aquaculture commodities in FSM are produced for livelihoods from coastal waters. These commodities include black pearls and marine ornamentals, such as cultured coral and giant clams. Hatchery production of sea cucumbers (sandfish) is also underway in FSM.

Existing and projected environmental features

Increasing SST, rainfall and ocean acidification are expected to reduce the suitability of coastal waters for culturing pearls, ornamental products and sea cucumbers {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Annual rainfall (mm)	4588[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Sea surface temperature (°C)	29.1	+0.6 to +0.8%	+0.7 to +0.8%	+1.2 to +1.6%	+2.2 to +2.7%
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

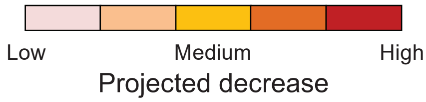
* Approximates A2 in 2050; a = data for Pohnpei.

Projected changes in aquaculture production

The coastal aquaculture commodities produced in FSM are likely to be affected adversely by climate change {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Pearls	Livelihoods			
Marine ornamentals	Livelihoods			
Sea cucumbers	Livelihoods			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The local surface tuna fishery contributed 3.3% to the GDP of FSM in 2007, and the longline fishery provided a further 0.7% of GDP {Chapter 12}. Licence fees from foreign (and national) vessels involved in the surface fishery contributed > 10% to government revenue (GR), and fees from longline fleets contributed a further 1.3% of GR.

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Surface	7.8	3.3[a]	14.8	10.2[b]
Longline	1.7	0.7	2.2	1.3

* Information for 2007, when national GDP was USD 237 million (Gillett 2009)[1]; ** information for 2007, when total GR was USD 145 million; a = locally-based purse-seine fleets; b = includes fees from both foreign and domestic fleets.

Projected effects of climate change

The projected changes to GDP due to the effects of climate change on the distribution and abundance of skipjack tuna {Chapter 8, Table 8.4} could increase contributions from the catches of this species to GDP from ~ 3% to ~ 4% in 2035 and reduce these contributions to 2% in 2100 {Chapter 12}. The projected changes to government revenue could increase from 10% to up to 12% in 2035, but fall to 8% by 2100 under the A2 scenario.

Projected changes to GDP (%)			Projected changes to GR (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
0 to +1	0	0 to -1	+1 to +2	0 to +1	-1 to -2

* Approximates A2 in 2050.

Food security

FSM is among the group of PICTs (Group 2) where the estimated sustainable production of fish and invertebrates from coastal habitats has the potential to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i]. However, it may be difficult to distribute the catch due to the distances between fishing areas and population centres {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in FSM is estimated to be 69 kg per person per year, significantly above the 35 kg per person per year recommended for good nutrition {Chapter 12}. The majority of this fish is provided by subsistence fishing.

Fish consumption per person (kg)			Animal protein from fish (%)		Fish provided by subsistence catch (%)	
National	Rural	Urban	Rural	Urban	Rural	Urban
69	77	67	80	83	77	73

Effects of population growth

The population in FSM is projected to remain relatively stable over this century and coastal fisheries are expected to easily supply the fish needed for food security. Large surpluses of fish are expected to continue to be available in 2035, 2050 and 2100.

Variable	2010	2035	2050	2100
Population (x 1000)	102	105	109	109
Fish available per person (kg/year)[a]	442	429	414	414
Surplus (kg/person/year)[b]	407	394	379	379

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The effects of climate change on coastal fisheries are likely to cause only minor reductions in the significant surplus of fish available for food. Even with the projected decreases in production of demersal fish of up to 50% by 2100 under the A2 emissions scenario, the large area of coral reef relative to population size will continue to supply sufficient coastal fish for food security {Chapter 12, Table 12.12}. Projected increases in tuna catch by the nearshore fishery are expected to further increase access to fish until 2050 under the A2 emissions scenario.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Livelihoods

Current contributions

Full-time and part-time jobs have been created through tuna fishing and processing in FSM, although they represent only a low percentage of total employment in the nation. Coastal fisheries also provide important opportunities to earn income for coastal communities throughout the country, with > 50% of households in representative coastal communities deriving their first or second incomes by catching and selling fish. Relatively few people are employed in aquaculture[4].

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
89	36	25	131	24	140	48	5	52	20

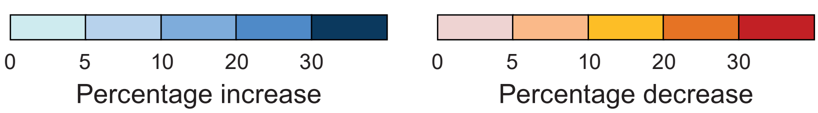
* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries and the nearshore component of coastal fisheries. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change			
	Oceanic fisheries**	Coastal fisheries		Aquaculture
		Nearshore pelagic fish	Other resources	(coastal)
Present*	⇧	⇧	⇩	⇧
2035	⬆	No effect	⬇	⬇
2050	⬆	⬇	⬇	⬇
2100	⬇	⬇	⬇	⬇

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due to their mainly subsistence role.



Adaptations and suggested policies

The plans FSM has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. maximise access to tuna, and the efficiency of local industrial fishing operations, to increase the contributions from oceanic fisheries resources to economic development and government revenue;
2. manage coastal fish habitats and fish stocks to maintain the good supply of fish for food security; and
3. increase the number of livelihoods that can be sustained by fishing, tourism and coastal aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E1	Full implementation of sustainable fishing effort schemes	E1, E2, E4–E6
E3	Immediate conservation management measures for bigeye tuna	E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

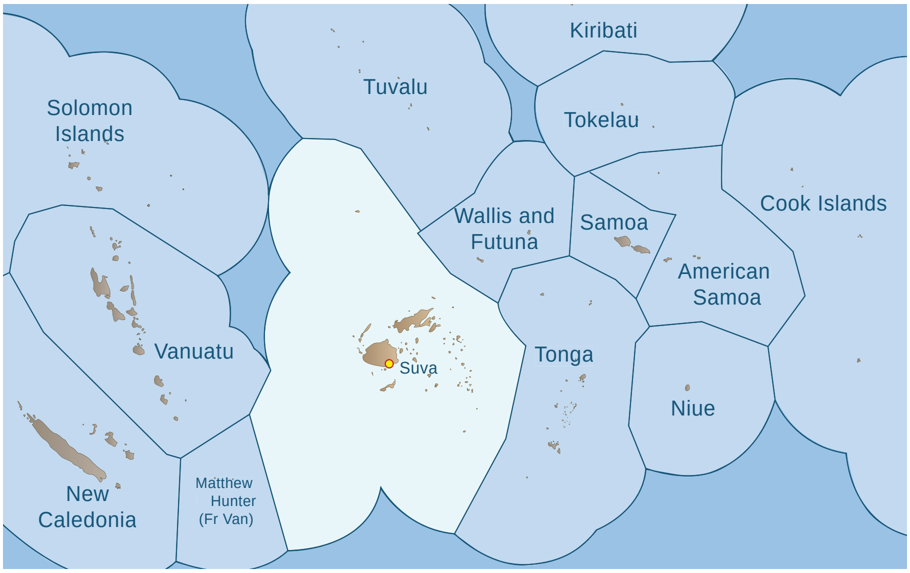
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F4	Allow for expansion of freshwater habitats	F4, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F8	Increase access to tuna for urban and rural populations	F8–F13, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.4 Fiji



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	848	978	1061	1332
Population growth rate[a]	0.5	0.5	0.5	0.4

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 1,229,728

Land area (km²) 18,272

Land as % of EEZ 1.5

Fisheries and aquaculture activities: Oceanic fisheries, coastal fisheries, freshwater and estuarine fisheries, coastal and freshwater aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; South Pacific Tuna and Billfish subcommittee; Melanesian Spearhead Group.

Surface climate and the ocean

Existing features

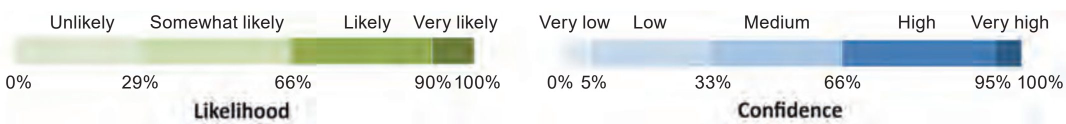
Fiji has a tropical climate {Chapter 2}. Recent air temperatures in Nadi have averaged 25.8°C and average rainfall is ~ 1800 mm per year. Fiji lies within the Archipelagic Deep Basins Province (ARCH) {Chapter 4, Figure 4.6}. The climate and ocean within this province are influenced by a complex current regime caused by the occurrence of many islands, archipelagos and seamounts. These formations divert oceanic circulation to create eddies, resulting in upwelling, downwelling and other mesoscale processes {Chapter 3, Section 3.2.9, Figure 3.1}. ARCH Province is characterised by a patchwork of nutrient-rich and nutrient-poor water bodies that can vary over short timeframes.

Projected changes to surface climate

Air temperatures and rainfall in Fiji are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	25.8 (Nadi)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1788 (Nadi)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	1.9	➤ Total number of tropical cyclones may decrease ➤ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Fiji, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Fiji relative to the long-term averages are expected to result in increases to sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	26.9[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

Fiji has a locally-based, industrial fishery operating within and outside its exclusive economic zone (EEZ), based mainly on longlining for albacore, yellowfin and bigeye tuna. Recent catches from this fishery have averaged 13,850 tonnes per year, worth > USD 67 million. Fiji also licenses foreign fleets to fish for tuna in its EEZ, although recent annual average catches by these fleets have been only ~ 250 tonnes. However, foreign vessels land significant catches (> 10,000 tonnes) of tuna in Fiji caught elsewhere in the region. See 'Coastal Fisheries' below for contributions of tuna to nearshore small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Longline	12,742	66.0
Pole-and-line	475	0.8
Other methods	76	0.2
Other oceanic fish[a]	558	0.6
Total	**13,851**	**67.6**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The productivity of the waters surrounding Fiji is variable and typical of the ARCH Province {Chapter 4, Section 4.3.4}. Coasts and islands influence a broad range of mesoscale processes (e.g. local boundary currents, jets, wind-driven upwelling, internal waves and tidal mixing) which commonly bring nutrients to surface waters {Chapter 3, Section 3.2.9}. The food webs for tuna and other large pelagic fish in the EEZ of Fiji are based on nutrients derived from these mesoscale processes, and to a lesser extent on runoff from high islands.

Projected changes to oceanic fish habitat

The area of the ARCH Province remains the same by definition. However, key components of the food web (net primary production and the biomass of zooplankton) are expected to decrease significantly under the B1 and A2 scenarios by 2100 in ARCH {Chapter 4, Table 4.3}.

ARCH feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Net primary production	-5	-8	-20	-33
Zooplankton biomass	-5	-6	-17	-26

* Approximates A2 in 2050.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Fiji are expected to increase in 2035 and 2100, relative to the 20-year average (1980–2000). Catches of bigeye tuna are projected to remain relatively stable until 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+26	+24	+33	+1	+1	-1

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Fiji are made up of four components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, Spanish mackerel, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 26,900 tonnes in 2007, worth USD 67.6 million. The commercial catch was 9500 tonnes. Demersal fish are estimated to make up 65% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	17,450	5270	630	3550	26,900	67.6
Contribution (%)[a]	65	20	2	13	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

Fiji has a significant area of coral reef {Chapter 5}, as well as mangroves, deepwater and intertidal seagrasses, and intertidal sand and mud flats {Chapter 6} that support many important fisheries species.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	10,000*	425	16.5	n/a

* Estimate only; a = includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Fiji, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	< -5	-5 to -10	-10 to -20

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish, targeted invertebrates, and intertidal and subtidal invertebrates in Fiji are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relatively heavy reliance on demersal fish, offset to some extent by the projected increase in productivity of the nearshore pelagic component of the fishery. As a result, total catches from coastal fisheries in Fiji are projected to increase slightly under both scenarios in 2035 but decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	65	-3.5	-2	-20	-13	-35	-23
Nearshore pelagic fish	20	+17.5	+3	+20	+4	+10	+2
Targeted invertebrates	2	-3.5	-0.07	-10	-0.2	-20	-0.5
Inter/subtidal invertebrates	13	0	0	-5	-0.7	-10	-1
Total catch[a]			**+1**		**-10**		**-23**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Fiji; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in Fiji are freshwater clams (kai), freshwater prawns (*Macrobrachium* and *Palaemon*), flagtails (jungle perch), eels, tilapia, gobies and carp. These species are mostly taken by subsistence and commercial fisheries from rivers, lakes and estuaries. The estimated annual freshwater fish catch in 2007 was 4146 tonnes, worth USD 4.3 million {Chapter 10}.

Existing freshwater and estuarine fish habitat

The larger rivers in Fiji provide a wide range of freshwater and estuarine fish habitats that support diverse fish communities {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km^2)	River length (km)
Viti Levu	Rewa	2918	145
Vanua Levu	Dreketi	317	65

Projected changes to freshwater and estuarine fish habitat

The projected increase in rainfall for Fiji {Chapter 2, Section 2.5.2} is expected to result in increases in the area and quality of freshwater fish habitats. The greatest increases in freshwater habitats are expected to occur under A2 in 2100 {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	B1 2100*	A2 2100
-5 to +5	-5 to +5	+5 to +20

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Higher projected rainfall and river flows are expected to increase production of freshwater and estuarine fisheries in Fiji in 2100 under A2. River flow increases the availability and quality of habitats, provides cues for for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
0	0	+12.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

The main aquaculture commodities in Fiji include those produced for livelihoods in coastal waters, such as black pearls, shrimp, seaweed and marine ornamentals, and *Macrobrachium* grown in ponds. Tilapia, carp and milkfish are also produced in freshwater ponds for food security. There is potential for expanding village-level milkfish capture and culture operations and culture of live rock. Sea ranching trials for sea cucumbers (sandfish) are now underway.

Aquaculture commodity	Annual production (tonnes)	Annual value (USD)
Nile tilapia[a]	160	217,000
Seaweed[a]	135	71,000
Shrimp[a]	30	317,000
Macrobrachium[b]	13	183,000

a = Based on 1998–2007 data; b = based on 2004–2007 data.

Existing and projected environmental features

Increasing SST, rainfall and ocean acidification are expected to reduce the number of sites where seaweed can be grown successfully, and reduce the survival and growth of ornamental products (e.g. coral fragments and live rock), pearl oyster spat and sea cucumbers {Chapter 11}. Higher rainfall and air temperatures are expected to have positive effects on pond aquaculture.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	25.8[a]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	1788[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Cyclones (no. per year)	1.9	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	26.9	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

* Approximates A2 in 2050; a = data for Nadi.

Projected changes in aquaculture production

The projected effects of climate change on aquaculture in Fiji are mixed. The commodities grown in coastal waters for livelihoods are likely to be affected adversely by increases in SST, rainfall, ocean acidification and possibly stronger storm surge from more severe cyclones {Chapter 11, Table 11.5}. However, shrimp farming in Fiji may benefit in the medium term from increasing temperatures that increase growth rates {Chapter 11}. Pond aquaculture of tilapia and milkfish is expected to be enhanced by increased rainfall, river flows, and warmer temperatures, provided ponds are located where they will not be affected by floods or storm surge.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Tilapia	Food security	↑	↑	↑
Milkfish	Food security	↑	↑	↑
Pearls	Livelihoods	↓	↓	↓
Seaweed	Livelihoods	↓	↓	↓
Shrimp	Livelihoods	↑	↓	↓
Marine ornamentals	Livelihoods	↓	↓	↓
Freshwater prawn	Livelihoods	↑	↓	↓
Sea cucumbers	Livelihoods	↓	↓	↓

* Approximates A2 in 2050.

Low Medium High
Projected increase

Low Medium High
Projected decrease

Economic and social implications

Economic development and government revenue

Current contributions

The industrial longline fishery for tuna contributed USD 5.9 million (0.2%) to the gross domestic product (GDP). Licence fees from foreign purse-seine and longline vessels contributed 0.3% to government revenue (GR) in 2007 {Chapter 12}.

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Surface	0	0	0.26	0.3
Longline	5.9	0.2	0.005	< 0.01

* Information for 2007, when national GDP was USD 3290 million (Gillett 2009)[1]; ** information for 2007, when total GR was USD 920 million.

Projected effects of climate change

The projected changes to GDP and government revenue due to the effects of climate change on tuna resources are expected to be negligible because the industrial tuna fishery makes only a minor contribution to the relatively large economy of Fiji {Chapter 12}.

Food security

Fiji is among the group of PICTs (Group 3) where the estimated sustainable production of fish and invertebrates from coastal habitats is unable to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Fiji is estimated to be 21 kg per person per year, well below the recommended levels for good nutrition[1]. In rural areas, ~ 50% of this consumption is supplied from subsistence fishing. At present, coastal habitats in Fiji are estimated to be able to supply a small surplus (5 kg per person) above the recommended consumption level of 35 kg per person per year.

Fish consumption per person (kg)			Fish provided by subsistence catch (%)	
National	**Rural**	**Urban**	**Rural**	**Urban**
21	25	15	52	7

Effects of population growth

Fiji will have an increasing total demand for fish for food security due to the predicted growth of its population. Consequently, the current estimated fish surplus is expected to change to a shortfall of 3 kg per person per year in 2050 and 9 kg per person per year in 2100.

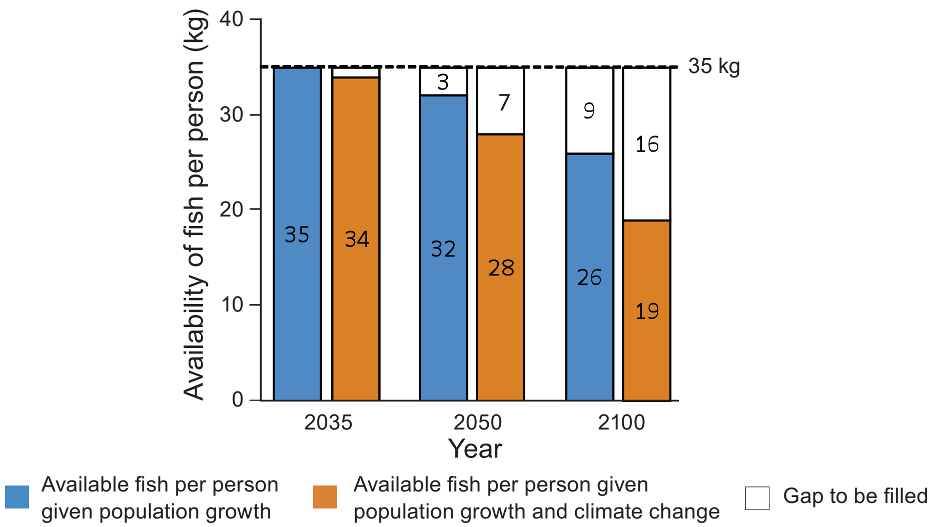
Variable	2010	2035	2050	2100
Population (x 1000)	848	978	1061	1332
Fish available per person (kg/year)[a]	40	35	32	26
Gap (kg/person/year)[b]	(+5)	0	3	9

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

Fiji faces further declines in the fish available per person due to the combined effects of population growth and climate change. By 2050, the effects of climate change on coastal fisheries production {Chapter 9} are expected to cause the gap between the fish needed per person for good nutrition, and the fish available from coral reefs, to increase from 3 to 7 kg per person per year. By 2100, the gap is projected to increase from 9 to 16 kg per person per year.

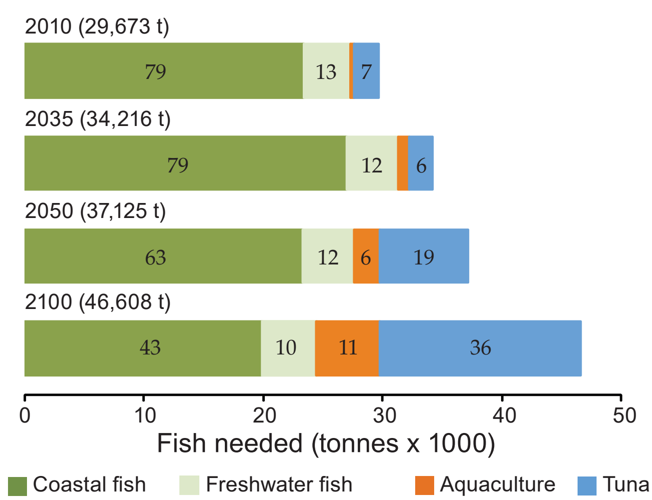
i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].



Relative effects of population growth and climate change on recommended annual fish consumption in Fiji.

Filling the gap

Increased access to tuna and bycatch from industrial fleets, and development of small pond aquaculture have the potential to supply the shortfall in the fish from coastal habitats required for food in Fiji. This gap will need to be filled mainly by tuna, however, because pond aquaculture is only expected to provide limited quantities of fish. The role of tuna in filling the gap becomes increasingly important in 2050 and 2100. Pond aquaculture is likely to be important where access to tuna remains difficult.



Fish (in tonnes) needed for future food security in Fiji, and the recommended contributions (%) of fisheries resources and aquaculture production required to meet future needs.

Fiji should plan to allocate an increasing proportion of the annual average tuna catch over time to provide the quantities of fish recommended for good nutrition of their population. These proportions reach 6% in 2035, increasing to 20% in 2050, and 36% by 2100.

Livelihoods

Current contributions

Large numbers of full-time and part-time jobs have been created through tuna fishing and processing in Fiji, although they represent only a low percentage of total employment in the nation due to the size of the population {Chapter 12}. Coastal fisheries also provide significant opportunities to earn income for coastal communities throughout the country, with > 90% of households in representative coastal communities earning their first or second income from catching and selling fish. Aquaculture provides jobs for > 500 people[4].

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	**2006**	**2008**	**2002**	**2006**	**2008**	**1st**	**2nd**	**Both**	**2007**
893	330	150	1496	2200	1250	70	23	93	550

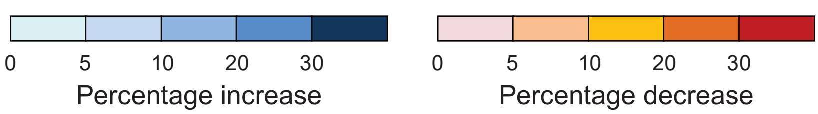
* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries, freshwater fisheries, and pond and coastal aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario					
	Oceanic fisheries**	Coastal fisheries		Freshwater fisheries	Aquaculture	
		Nearshore pelagic fish	Other resources		Ponds	Coastal
Present*	↑	↑	↓	↑	↑	↑
2035	↑	No effect	↓	↑	↑	↓
2050	No effect	↓	↓	↑	↑	↓
2100	↓	↓	↓	↑	↑	↓

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches.



Adaptations and suggested policies

The plans Fiji has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. secure access to the tuna required by canneries and increase the efficiency of locally-based fleets;
2. increase access to diverse sources of fish to provide the fish needed for food security for both rural and urban communities; and
3. increase the number of livelihoods that can be based on fishing and processing tuna, and on pond and coastal aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

<table>
<tr><th>Adaptation no. (Section 3.2)</th><th>Summary of adaptation</th><th>Supporting policy no. (Section 3.3)</th></tr>
<tr><td>E2</td><td>Diversify sources of fish for canneries</td><td>E1–E5, E7</td></tr>
<tr><td>E3</td><td>Immediate conservation management measures for bigeye tuna</td><td>E7, E8</td></tr>
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<tr><td>E5</td><td>Environmentally-friendly fishing operations</td></tr>
<tr><td>E6</td><td>Gender-sensitive fish processing operations</td></tr>
<tr><td>E7</td><td>Safety at sea</td><td>E10</td></tr>
<tr><td>E8</td><td>Climate-proof infrastructure</td><td>E11</td></tr>
<tr><td>E9</td><td>Pan-Pacific tuna management</td><td>E2</td></tr>
</table>

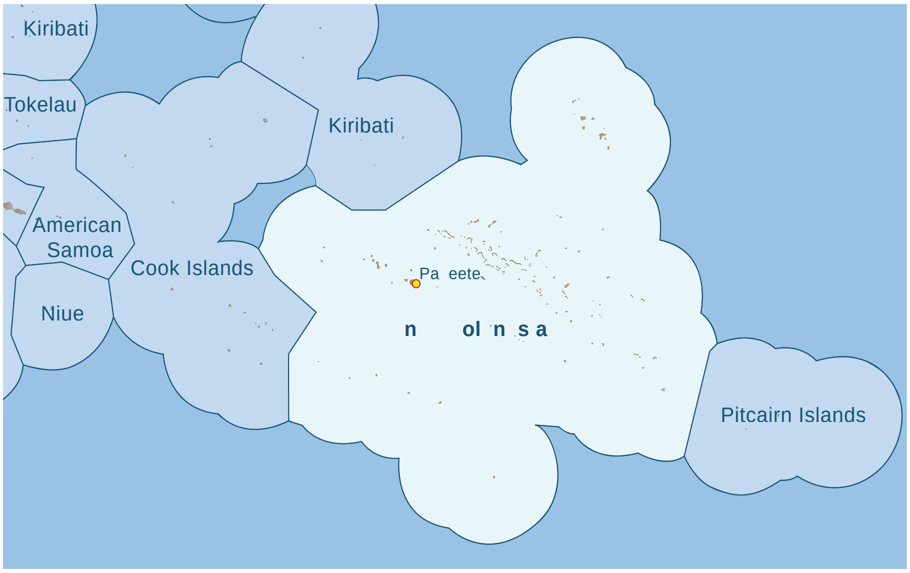
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F4	Allow for expansion of freshwater habitats	F4, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F7	Manage freshwater and estuarine fisheries to harness opportunities	
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	F13–16, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.5 French Polynesia



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	269	331	349	379
Population growth rate[a]	1.2	0.6	0.3	0.4

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 4,200,000

Land area (km²) 3521

Land as % of EEZ 0.084

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries, with some limited freshwater and estuarine fisheries and coastal aquaculture.

Membership of regional fisheries management arrangements: Western and Central Pacific Fisheries Commission.

Surface climate and the ocean

Existing features

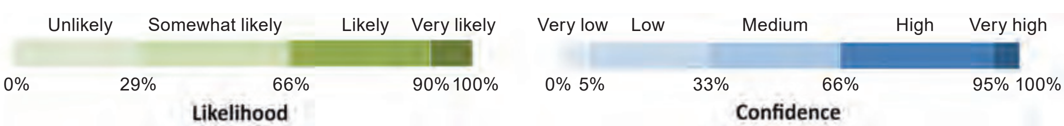
French Polynesia has a tropical-subtropical climate {Chapter 2}. Recent air temperatures in Tahiti-Faa'a have averaged 26.5°C and average rainfall is ~ 1800 mm per year. French Polynesia lies within the South Pacific Subtropical Gyre Province (SPSG) {Chapter 4, Figure 4.6}. The SPSG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}.

Projected changes to surface climate

Air temperatures in French Polynesia are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}. Rainfall is expected to decrease during summer and increase during winter under all scenarios.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	26.5 (Tahiti-Faa'a)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1807 (Tahiti-Faa'a)	-5 to -10%	-5 to -20%	-5 to -20%	-5 to -20%
		More extreme wet and dry periods			
Cyclones (no. per year)	n/a	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the southern subtropical Pacific, see www.cawcr.gov.au/projects/PCCSP; n/a = data not available.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding French Polynesia relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	25.9[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

French Polynesia has a locally-based, industrial oceanic fishery within its exclusive economic zone (EEZ), primarily longlining for albacore tuna. Recent average catches by this fishery have been > 6500 tonnes per year, worth ~ USD 25.7 million. French Polynesia has also licensed foreign fleets to fish for tuna in its EEZ, although recent average total annual catches have been low (~ 300 tonnes). Significant catches are also landed by foreign vessels in French Polynesia {Chapter 12}. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Longline	4170	21.6
Pole-and-line	613	1
Other methods	985	2.3
Other oceanic fish[a]	750	0.8
Total	**6518**	**25.7**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

French Polynesia's EEZ lies within the generally nutrient-poor waters of the SPSG Province {Chapter 4, Figure 4.6}. This province is characterised by downwelling and low nitrate concentrations in deeper waters. Net primary production is low, particularly in summer when there is the formation of a marked thermocline {Chapter 4, Section 4.4.3}. Local upwelling around islands can result in small areas of enriched surface productivity. In general, however, the SPSG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the SPSG Province is projected to increase and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease in SPSG {Chapter 4, Table 4.3}.

SPSG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+4	+7	+7	+14
Location	Poleward extension of southern limit			
Net primary production	-3	-5	-3	-6
Zooplankton biomass	-3	-4	-5	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of French Polynesia are expected to increase significantly in 2035 and 2100, relative to the 20-year average (1980–2000). However, catches of bigeye tuna are projected to decrease under both scenarios in 2035 and 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward and to be more abundant at the edges of the SPSG Province.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+41	+49	+77	-2	-8	-12

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of French Polynesia are made up of four components: demersal fish (bottom-dwelling fish associated with coral reef and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be ~ 6880 tonnes in 2007, worth > USD 36 million. The commercial catch was 4000 tonnes. Demersal fish are estimated to make up > 50% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	3666	2582	104	530	6882	36.2
Contribution (%)[a]	53	37.5	1.5	8	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by tuna species.

Existing coastal fish habitat

French Polynesia has > 15,000 km^2 of coral reef habitat {Chapter 5}, as well as deepwater and intertidal seagrasses, and intertidal sand flats {Chapter 6} that support many important fisheries species.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	15,126	-	29	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, seagrasses and intertidal flats in French Polynesia, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	< -5	-5 to -10	-10 to -20

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish, targeted invertebrates, and intertidal and subtidal invertebrates in French Polynesia are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the heavy reliance on demersal fish, offset to some extent by the projected increase in productivity of the nearshore pelagic component of the fishery. As a result, total catches from coastal fisheries in French Polynesia are projected to increase under both scenarios in 2035 but decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	53	-3.5	-2	-20	-11	-35	-18.5
Nearshore pelagic fish	37	+17.5	+7	+20	+8	+10	+4
Targeted invertebrates	2	-3.5	< -0.1	-10	-0.2	-20	-0.4
Inter/subtidal invertebrates	8	0	0	-5	-0.4	-10	-0.8
Total catch[a]			**+5**		**-3.5**		**-16**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in French Polynesia; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in French Polynesia are flagtails (jungle perch), eels, gobies, 'whitebait', tilapia and *Macrobrachium*. These species are mostly caught by subsistence fishers from lowland rivers and estuaries. The estimated annual freshwater fish catch in 2007 was 100 tonnes, worth ~ USD 490,000 {Chapter 10}.

Existing freshwater and estuarine fish habitat

The largest river in French Polynesia, Papenoo, is 23 km in length and provides a range of freshwater and estuarine fish habitats that support fish communities {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km^2)	River length (km)
Tahiti	Papenoo	91	23

Projected changes to freshwater and estuarine fish habitat

The projected changes in rainfall for French Polynesia {Chapter 2, Section 2.5.2} are expected to increase variability in the area and quality of all freshwater fish habitats {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	B1 2100*	A2 2100
-5 to +10	-5 to +10	-10 to > +20

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Projected changes to rainfall and river flow patterns are expected to result in slightly improved production from freshwater and estuarine fisheries in French Polynesia under both scenarios in 2035 and B1 in 2100. This trend is expected to increase further under A2 in 2100 as greater year-round river flow improves the availability and quality of habitats, provides better cues for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
+2.5	+2.5	+7.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

The aquaculture commodities produced in French Polynesia are dominated by black pearls and mother-of-pearl shell. Other commodities produced for livelihoods in coastal waters include shrimp, marine ornamentals (giant clams) and marine fish. There is potential to increase the production of some forms of coastal aquaculture, and to develop freshwater pond aquaculture.

Aquaculture commodity	Annual production (tonnes)	Annual value (USD million)
Pearl[a]	12.5	145
Mother-of-pearl shell[b]	1505	0.4
Shrimp[b]	48	1

a = Based on 1998–2007 data; b = based on 2004–2007 data.

Existing and projected environmental features

Increasing SST and ocean acidification are expected to adversely affect the conditions required for good survival and growth of pearl oyster spat and ornamental species (e.g. giant clams and coral fragments). Acidification of the ocean may also affect the formation of nacre by pearl oysters, and therefore pearl quality {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	25.9	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

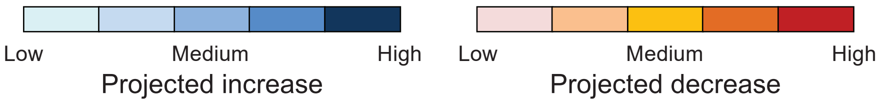
* Approximates A2 in 2050.

Projected changes in aquaculture production

The projected increases in SST and ocean acidification are eventually expected to result in decreased coastal aquaculture production in French Polynesia {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Pearls	Livelihoods			
Shrimp	Livelihoods			
Marine ornamentals	Livelihoods			
Marine fish	Livelihoods			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The locally-based longline and surface fisheries for tuna and other large pelagic fish in French Polynesia made only very small contributions to gross domestic product (GDP) in 2007 due to the relatively large size of the economy {Chapter 12}. Licence fees from foreign vessels did not contribute to government revenue.

Industrial fishery	Contribution to GDP*	
	USD m	GDP (%)
Longline	5.6	0.09
Surface	0.3	< 0.01

* Information for 2007, when national GDP was USD 5478 million (Gillett 2009)[1].

Projected effects of climate change

The projected changes to GDP due to the positive effects of climate change on tuna resources are expected to be negligible because the industrial tuna fishery in French Polynesia makes only relatively minor contributions to the economy {Chapter 12}.

Food security

French Polynesia is among the group of PICTs (Group 2) where the estimated sustainable production of fish and invertebrates from coastal habitats has the potential to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}. However, it may

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

be difficult to distribute the catch to urban areas due to large distances between population centres and the many outlying atolls and islands in French Polynesia where coastal fish stocks are abundant {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in French Polynesia is estimated to be 70 kg per person per year[2], twice the recommended levels for good nutrition. At present, coral reefs and other coastal habitats in French Polynesia are estimated to be able to supply a surplus of 134 kg of fish per person per year above the recommended consumption level of 35 kg.

Fish consumption per person (kg)			Animal protein from fish (%)		Fish provided by subsistence catch (%)	
National	Rural	Urban	Rural	Urban	Rural	Urban
70	90	52	71	57	78	60

Effects of population growth

French Polynesia will have an increasing demand for fish for food security due to the predicted population growth. However, coastal habitats have the potential to continue to provide sufficient fish to meet the recommended requirements, and maintain the traditionally high levels of fish consumption, provided the catch can be distributed effectively {Chapter 12, Section 12.7.3}.

Variable	2010	2035	2050	2100
Population (x 1000)	269	331	349	379
Fish available per person (kg/year)[a]	169	137	130	120
Surplus (kg/person/year)[b]	134	102	95	85

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The effects of climate change on coastal fisheries are not expected to cause declines in the fish available per person that are great enough to affect food security in French Polynesia. The large area of coral reefs relative to population size will continue to supply sufficient coastal fish for food security even with projected decreases in production of demersal fish of up to 50% under the A2 scenario in 2100. Increased access to nearshore tuna resources should also provide access to more fish.

Livelihoods

Current contributions

Coastal fisheries provide > 25% of coastal households in French Polynesia with either their first or second source of income. Aquaculture (mainly pearl farming) employs 5000 people[4]. The number of full-time and part-time jobs on tuna vessels is undetermined.

Coastal households earning income from fishing (%)			Jobs in aquaculture*
1st	2nd	Both	2007
15	11	27	5000

* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and coastal aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario				
	Oceanic fisheries**	Coastal fisheries		Freshwater fisheries	Aquaculture (coastal)
		Nearshore pelagic fish	Other resources		
Present*	⇧	⇧	⇩	⇧	⇧
2035	⬆	⬆	⬇	⬆	⬇
2050	⬆	⬆	⬇	⬆	⬇
2100	⬆	⬆	⬇	⬆	⬇

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches.

Adaptations and suggested policies

The plans French Polynesia has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. maximise access to tuna, and the efficiency of tuna fishing operations, to provide fish for economic development and continued food security;
2. manage coastal fish habitats and fish stocks to ensure that they continue to provide fish for food security; and
3. increase the number of livelihoods that can be based on fishing, tourism, and coastal aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E3	Immediate conservation management measures for bigeye tuna	E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

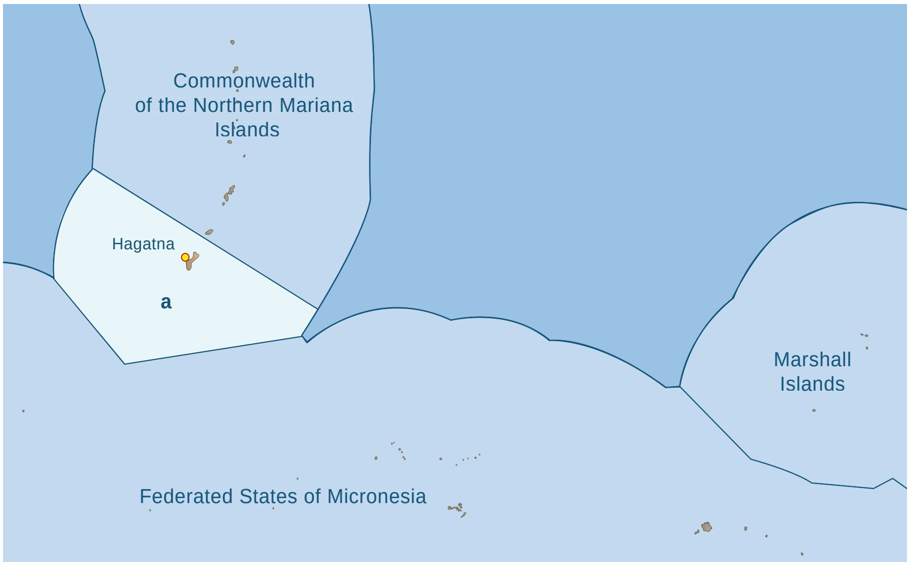
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F4	Allow for expansion of freshwater habitats	F4, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F7	Manage freshwater and estuarine fisheries to harness opportunities	
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.6 Guam



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	187	250	268	296
Population growth rate[a]	2.7	1.1	0.4	0

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 214,059

Land area (km²) 541

Land as % of EEZ 0.25

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries, with some freshwater and estuarine fisheries and coastal and pond aquaculture.

Membership of regional fisheries management arrangements: Western Pacific Regional Fisheries Management Council; Western and Central Pacific Fisheries Commission (participating territory).

Surface climate and the ocean

Existing features

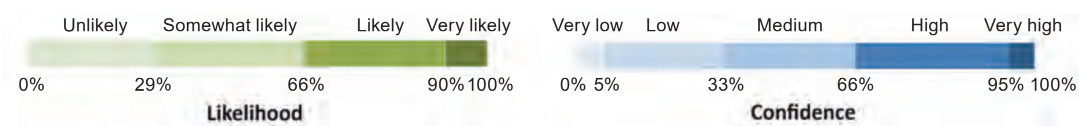
Guam has a tropical climate {Chapter 2}. Recent air temperatures have averaged 27.7°C and average rainfall is > 2150 mm per year. Guam lies within the North Pacific Tropical Gyre Province (NPTG) {Chapter 4, Figure 4.6}. The NPTG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}. As a result, the primary production is very low.

Projected changes to surface climate

Air temperatures and rainfall in Guam are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.7	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	2168	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	n/a	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Guam, see www.cawcr.gov.au/projects/PCCSP; n/a = data not available.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Guam relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the North Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	28.7[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in North Pacific gyre	Continued increase in strength of North Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

Guam has a small, locally-based oceanic fishery within its exclusive economic zone (EEZ), mainly trolling for skipjack tuna. Recent average catches for this fishery have been 114 tonnes per year, worth ~ USD 250,000. Guam also licenses foreign fleets to fish in its EEZ, but recent average annual catches have been low (17 tonnes). See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD)* 2004–2008
Tuna		
Troll	103	240,000
Other oceanic fish[a]	11	10,800
Total	**114**	**250,800**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The NPTG Province is characterised by low primary production due to the convergence of surface waters and downwelling. Local upwelling near islands can result in enriched surface productivity {Chapter 4, Section 3.2.4}. In general, however, the NTPG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the NPTG Province is projected to increase only slightly and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease significantly in NPTG, particularly under the A2 emissions scenario in 2100 {Chapter 4, Table 4.3}.

NPTG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+1	+1	+1	+1
Location	Poleward			
Net primary production	-3	-5	-11	-22
Zooplankton biomass	-3	-4	-10	-18

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Guam are expected to increase in 2035 and B1 in 2100, relative to the 20-year average (1980–2000). Catches are expected to decrease under the A2 scenario in 2100 {Chapter 8, Section 8.7}.

Projected change in skipjack tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100
+16	+10	-8

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Guam are made up mainly of three components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 114 tonnes in 2007, worth > USD 412,000. The commercial catch was 44 tonnes. Nearshore pelagic fish are estimated to make up ~ 70% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	33	77	0	4	114	0.41
Contribution (%)[a]	29	68	0	3	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch comprised equally of tuna and non-tuna species.

Existing coastal fish habitat

Guam has relatively small areas of coral reefs {Chapter 5}, mangroves, deepwater and intertidal seagrasses, and intertidal sand and mud flats {Chapter 6}.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	238	0.7	31	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Guam, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-60	-70
Seagrass area	-5 to -20	-5 to -35	-10 to -50

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish, nearshore pelagic fish and intertidal and subtidal invertebrates in Guam are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the projected decrease in the productivity of all coastal fishery components. As a result, total catches from coastal fisheries in Guam are projected to decrease slightly under both scenarios in 2035 and continue to decline under both scenarios in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	29	-3.5	-1	-20	-6	-35	-10
Nearshore pelagic fish	68	0	0	-10	-7	-17.5	-12
Inter/subtidal invertebrates	3	0	0	-5	-0.2	-10	-0.3
Total catch[a]			**-1**		**-13**		**-22**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Guam; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in Guam are eels, tilapia, milkfish and *Macrobrachium*. These species are mostly harvested by subsistence fishing. The estimated annual freshwater fish catch in 2007 was 3 tonnes, worth USD 10,000 {Chapter 10}.

Existing freshwater and estuarine fish habitat

The largest river in Guam, Talofofo, has a limited range of freshwater and estuarine fish habitats and supports a moderate diversity of fish and invertebrate species {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km^2)	River length (km)
Guam	Talofofo	60	12.6

Projected changes to freshwater and estuarine fish habitat

The projected increase in rainfall for Guam {Chapter 2, Section 2.5.2} is expected to result in increases in the area and quality of all freshwater fish habitats. The greatest increases in freshwater habitats are expected to occur under A2 in 2100 {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	**B1 2100***	**A2 2100**
-5 to +10	-5 to +10	-5 to +20

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Higher projected rainfall and river flows are expected to result in slightly improved production from freshwater and estuarine fisheries in Guam. Higher river flow increases the availability and quality of habitats, provides better cues for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	**B1 2100***	**A2 2100**
0 to +2.5	+2.5	+7.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

Aquaculture commodities produced in Guam include tilapia and 30–80 tonnes of milkfish per year grown in freshwater ponds for food. Shrimp is the main commodity produced by coastal aquaculture. There is potential for further pond aquaculture of tilapia for food security.

Existing and projected environmental features

Higher rainfall and air temperatures are expected to have positive effects on pond aquaculture. However, increasing SST, rainfall and storm intensity are expected to reduce the survival and growth of shrimp in the long term due to increased incidence of diseases and possible damage to farm infrastructure {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.7	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	2168	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Cyclones (no. per year)	n/a	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	28.7	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7

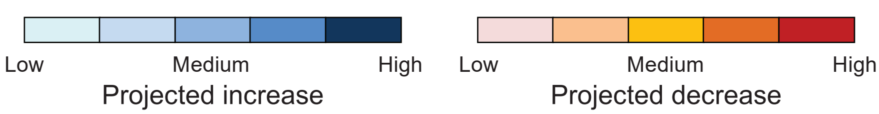
* Approximates A2 in 2050; n/a = no data available.

Projected changes in aquaculture production

Pond aquaculture is expected to be enhanced by increased rainfall, river flows and warmer temperatures. Shrimp farming may eventually be affected adversely by increases in SST and rainfall and possibly stronger storm surge from more severe cyclones {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Tilapia	Food security			
Milkfish	Food security			
Shrimp	Livelihoods			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The small skipjack tuna fishery in Guam does not contribute to gross domestic product (GDP) (USD 3679 million) or government revenue (GR) (USD 428 million) {Chapter 12}.

Projected effects of climate change

The effects of climate change on the distribution and abundance of skipjack tuna {Chapter 8} are not expected to result in noticeable contributions to GDP and GR due to the large size of the national economy {Chapter 12}.

Food security

Guam is among the group of PICTs (Group 3) where the estimated sustainable production of fish and invertebrates from coastal habitats is unable to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Guam is estimated to be 27 kg per person per year[1], somewhat below the level recommended for good nutrition. Because coastal habitats in Guam are estimated to be able to supply only 4 kg of fish per person per year, fresh and imported canned tuna provides most of the fish consumed.

Effects of population growth

Guam will have a rapidly increasing total demand for fish for food due to the predicted population growth. The current shortfall between the fish available from coral reef habitats and the fish required for good nutrition is 31 kg per person per year. This gap will increase for the remainder this century.

Variable	2010	2035	2050	2100
Population (x 1000)	187	250	268	296
Fish available per person (kg/year)[a]	4	3	3	2
Gap (kg/person/year)[b]	31	32	32	33

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

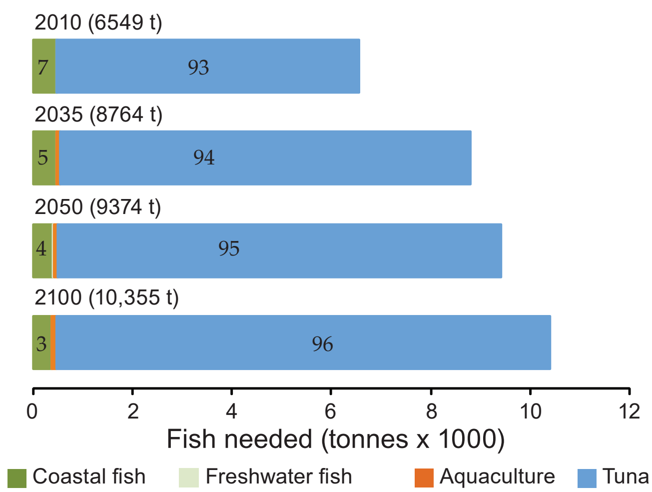
Additional effects of climate change

Guam faces further declines in the fish available per person from coastal habitats due to the combined effects of population growth and climate change. However, the projected declines in coastal fish production have little effect on the fish available per person compared to the effects of population growth.

Filling the gap

Tuna is the main resource available to Guam to help supply the shortfall in fish for food from coastal habitats. Pond aquaculture is only expected to be able to provide minor quantities of additional fish.

Given the limited existing catch of skipjack (~ 100 tonnes per year), the vast majority of fish needed to provide 35 kg of fish per person per year would need to be imported. However, because GDP per capita is relatively high, many people in Guam will have the ability to purchase other sources of animal protein and may not need 35 kg of fish per year for good nutrition.



Fish (in tonnes) needed for future food security in Guam, and the recommended contributions (%) of fisheries resources and aquaculture production required to meet future needs.

Livelihoods

Current contributions

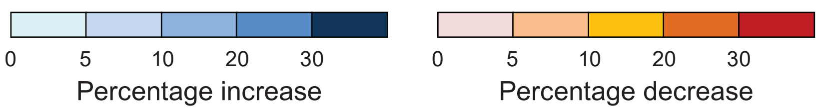
The total number of full-time and part-time jobs created through tuna fishing and processing in Guam has not been determined but is expected to only represent a very low percentage of total employment. Coastal fisheries also provide some opportunities to earn income for coastal communities, and 20 jobs have been created by aquaculture[4].

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and pond aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario				
	Oceanic fisheries**	Coastal fisheries		Aquaculture	
		Nearshore pelagic fish	Other resources	Ponds	Coastal
Present*	⇧	⇧	⇩	⇧	⇧
2035	↑	No effect	↓	↑	↓
2050	No effect	↓	↓	↑	↓
2100	↓	↓	↓	↑	↓

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due to their subsistence role.



Adaptations and suggested policies

The plans Guam has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. improve access to tuna, and manage coastal fish habitats and fish stocks, to maximise future contributions of fish to food security; and
2. increase the number of livelihoods that can be based on fishing, tourism and pond aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E3	Immediate conservation management measures for bigeye tuna	E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E7	Safety at sea	E10
E9	Pan-Pacific tuna management	E2

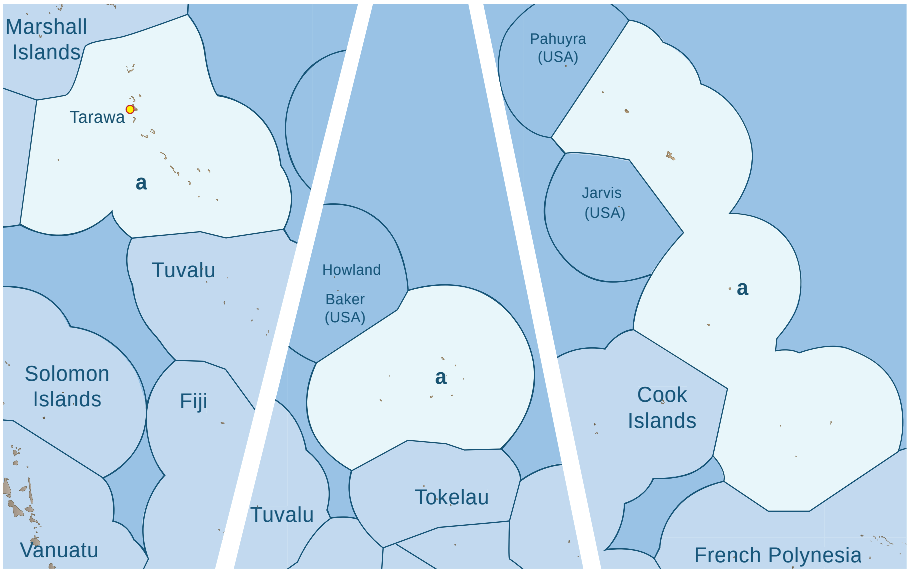
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F4	Allow for expansion of freshwater habitats	F4, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F7	Manage freshwater and estuarine fisheries to harness opportunities	
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	F13–16, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.7 Kiribati



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	101	145	163	211
Population growth rate[a]	1.8	1.1	0.8	0.2

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 3,550,000

Land area (km²) 810

Land as % of EEZ 0.02

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries, with some coastal aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Parties to the Nauru Agreement.

Surface climate and the ocean

Existing features

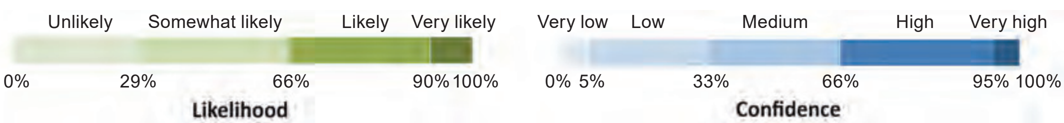
Kiribati has a tropical climate {Chapter 2}. Recent air temperatures in Tarawa have averaged 28.3°C and average rainfall is ~ 2100 mm per year. Kiribati lies within the Pacific Equatorial Divergence Province (PEQD) {Chapter 4, Figure 4.6}. The PEQD Province is generated by the effects of the earth's rotation on the South Equatorial Current, which results in significant upwelling of nutrients {Chapter 4, Figure 4.3}. These conditions create the richest surface waters in the region.

Projected changes to surface climate

Air temperatures and rainfall in Kiribati are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	28.3 (Tarawa)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	2121 (Tarawa)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			

* Approximates A2 in 2050; a = for more detailed projections of rainfall and air temperature in the vicinity of Kiribati, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Kiribati relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents, such as the South Equatorial Current, and the area and location of PEQD, are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	29.2[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	SEC decreases at equator; EUC becomes shallower; SECC decreases and retracts westward			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset; SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current.

Oceanic fisheries

Recent catch and value

The locally-based tuna fishery within Kiribati's exclusive economic zone (EEZ) has recently produced annual average catches (2004–2008) of almost 12,000 tonnes per year, worth > USD 21 million. Kiribati also licenses foreign fleets to fish in its EEZ. The average total annual catch of foreign purse-seine fleets exceeded 180,000 tonnes between 1999 and 2008, valued at USD 153 million per year {Chapter 12}. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Troll	6263	14.5
Purse-seine	5515	6.5
Longline	10	0.05
Other oceanic fish[a]	2	0.002
Total	**11,790**	**21.052**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The PEQD Province is characterised by high-salinity, nutrient-rich waters, and an abundance of phytoplankton {Chapter 4, Figure 4.7}. However, primary production in PEQD is limited by low iron concentrations {Chapter 4, Figure 4.9}. The convergence of PEQD and the Western Pacific Warm Pool creates prime feeding areas for tuna {Chapters 4 and 8}. Changes in the position of this convergence zone due to the El Niño-Southern Oscillation have a major influence on the abundance of tuna in the EEZ of Kiribati {Chapter 8}.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the PEQD Province is projected to contract and the convergence zone with the Warm Pool is expected to move eastward. However, there are likely to be only minor changes in the key components of the food web for tuna (e.g. net primary production and zooplankton biomass) in PEQD {Chapter 4, Table 4.3}.

PEQD feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	-20	-27	-30	-50
Location	Eastwards			
Net primary production	0	0	+2	+4
Zooplankton biomass	-2	-2	-3	-6

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Kiribati are expected to increase significantly in 2035 and 2100, relative to the 20-year average (1980–2000). However, catches of bigeye tuna are projected to decrease progressively under both scenarios in 2035 and 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+37	+43	+24	-1	-5	-17

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Kiribati are made up of four components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 20,700 tonnes in 2007, worth > USD 47 million. The commercial catch was 7000 tonnes. Demersal fish are estimated to make up > 70% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	15,075	4250	60	1315	20,700	47
Contribution (%)[a]	73	20	< 1	6	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by tuna species.

Existing coastal fish habitat

Kiribati has a large area of coral reefs {Chapter 5}, as well as small areas of mangroves, deepwater and intertidal seagrasses, and intertidal flats {Chapter 6} that support many important fisheries species.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	4320	2.6	n/a	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Kiribati, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area[c]	10	50	60
Seagrass area[c]	< -5	-5 to -10	-10 to -20

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs; c = indicative estimates from Fiji and French Polynesia {Chapter 6}.

Projected changes in coastal fisheries production

Fisheries for demersal fish, targeted invertebrates, and intertidal and subtidal invertebrates in Kiribati are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relatively heavy reliance on demersal fish, balanced somewhat by the projected increase in productivity of nearshore pelagic fish. As a result, total catches from coastal fisheries in Kiribati are projected to increase slightly under both scenarios in 2035 but decline in 2100, particularly under the A2 scenario in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	73	-3.5	-2.5	-20	-14.5	-35	-26
Nearshore pelagic fish	20	+17.5	+3.5	+20	+4	+10	+2
Targeted invertebrates	< 1	-3.5	-0.1	-10	-0.3	-20	-0.6
Inter/subtidal invertebrates	6	0	0	-5	-3	-10	-6
Total catch[a]			**+1**		**-14**		**-30**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Kiribati; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Kiribati has no freshwater or estuarine fisheries.

Aquaculture

Recent and potential production

Aquaculture commodities in Kiribati are mainly limited to seaweed and marine ornamentals produced in coastal waters for livelihoods. Milkfish are also reared in brackishwater ponds. Pilot projects for culturing black pearls, sea cucumbers and trochus are also underway. Trials are also in progress to improve the production of saltwater-tolerant strains of tilapia in brackishwater ponds.

Aquaculture commodity	Annual production (tonnes)	Annual value (USD)
Seaweed	790	471,000
Milkfish	127	228,500

Based on 1998–2006 data.

Existing and projected environmental features

Increasing SST, rainfall and ocean acidification are expected to reduce the number of sites where seaweed can be successfully grown, and the survival and growth of ornamental products (e.g. giant clams), pearl oyster spat and sea cucumbers {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	28.3[a]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	2121[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Sea surface temperature (°C)	29.2	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

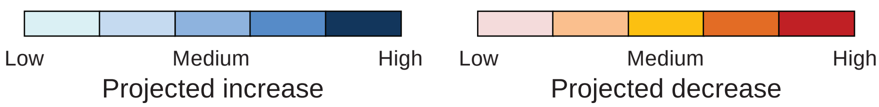
* Approximates A2 in 2050; a = data for Tarawa.

Projected changes in aquaculture production

The production of existing and potential commodities grown in coastal waters is likely to be affected adversely by increases in SST, rainfall and ocean acidification {Chapter 11, Table 11.5}. Milkfish farming in brackishwater ponds is expected to be favoured by higher air temperatures and increased rainfall {Chapter 11}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Existing				
Milkfish	Food security	↑	↑	↑
Seaweed	Livelihoods	↓	↓	↓
Marine ornamentals	Livelihoods	↓	↓	↓
Potential				
Tilapia	Food security	↑	↑	↑
Pearls	Livelihoods	↓	↓	↓
Sea cucumbers	Livelihoods	↓	↓	↓
Trochus	Livelihoods	↓	↓	↓

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

Licence fees from foreign purse-seine and longline tuna vessels contribute > 40% to government revenue (GR). Fishing for tuna by local fleets does not contribute to the gross domestic product of Kiribati {Chapter 12}.

Industrial fishery	Contribution to GR*	
	USD m	GR (%)
Surface and longline combined	51	42

* Information from 2007 (Gillett 2009)[1].

Projected effects of climate change

The preliminary modelling of the projected effects of climate change on the distribution and abundance of skipjack tuna indicate that there could be significant increases in the contributions of licence fees from foreign fishing vessels to government revenue {Chapter 12}. For example, contributions in 2035 are projected to increase by 11–18%, i.e. from ~ 40% to 50–60%.

Projected changes to GR (%)		
B1/A2 2035	**B1 2100***	**A2 2100**
+11 to +18	+13 to +21	+7 to +12

* Approximates A2 in 2050.

Food security

Kiribati is among the group of PICTs (Group 2) where the estimated sustainable production of fish and invertebrates from coral reef habitats has the potential to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i]. However, it may be difficult to distribute the catch due to the distances between fishing areas and population centres {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Kiribati is estimated to be 62 kg per person per year[2], well above the recommended levels for good nutrition. In rural areas, ~ 80% of this fish comes from subsistence catches and fish provides ~ 90% of dietary animal protein. At present, coral reefs in Kiribati are estimated to be able to supply 129 kg of fish per person per year.

Fish consumption per person (kg)			Animal protein from fish (%)		Fish provided by subsistence catch (%)	
National	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**
62	58	67	89	80	79	46

Effects of population growth

Assuming that the catch can be distributed effectively, coral reefs in Kiribati are presently estimated to be able to supply a surplus of 94 kg of fish per person per year above the recommended level of 35 kg. However, the predicted population growth for Kiribati will increase the total demand for fish for food security {Chapter 12, Section 12.7.3}. By 2100, the surplus in the potential estimated supply of fish from coral reefs will be reduced to 26 kg per person per year. Note that this surplus is reduced further because fishing is no longer permitted in the Phoenix Islands Protected Area.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Variable	2010	2035	2050	2100
Population (x 1000)	101	145	163	211
Fish available per person (kg/year)[a]	129	90	79	61
Surplus (kg/person/year)[b]	94	55	44	26

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

Kiribati faces further declines in the potential amount of fish available per person due to the combined effects of population growth and climate change. By 2100 under the A2 emissions scenario, production of fish and shellfish from coral reefs is projected to be 42 kg per person per year. This represents a potential surplus of 7 kg per person but such production is well below traditional fish consumption.

Filling the gap

Kiribati will need to find new ways to provide the fish needed to meet its traditionally high levels of consumption as population growth and climate change reduce the supply of coastal fish. Supplying sufficient fish in urban centres will depend largely on improving access to tuna. This can be achieved through increasing the catches made by the local fleet and negotiating with industrial vessels operating within Kiribati's EEZ to land a proportion of their tuna catch on a regular basis to supply the local market {Chapter 12}.

Livelihoods

Current contributions

Full-time and part-time jobs have been created through tuna fishing and processing in Kiribati, although they represent only a low percentage of total employment in the nation. Coastal fisheries also provide important opportunities to earn income with > 50% of representative rural households deriving their first or second income from fishing. Aquaculture enterprises presently employ 10 people[4].

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
39	15	15	47	80	70	33	25	58	10

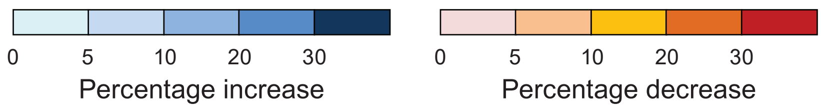
* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and coastal aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario					
	Oceanic fisheries**		Coastal fisheries			Aquaculture (coastal)
			Nearshore pelagic fish		Other resources	
	West	East	West	East		
Present*	⇧	⇧	⇧	⇧	⇩	⇧
2035	⬆	⬆	No effect	⬆	⬇	⬇
2050	No effect	⬆	⬇	⬆	⬇	⬇
2100	⬇	⬆	⬇	⬆	⬇	⬇

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches.



Adaptations and suggested policies

The plans Kiribati has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. maximise access to tuna, and the efficiency of fishing operations, to provide fish for economic development and food security;
2. manage coastal fish habitats and fish stocks to ensure that they continue to supply fish for food security; and
3. increase the number of livelihoods that can be based on fishing, tourism and coastal aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E1	Full implementation of sustainable fishing effort schemes	E1, E2, E4–E6
E3	Immediate conservation management measures for bigeye tuna	E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	E9
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

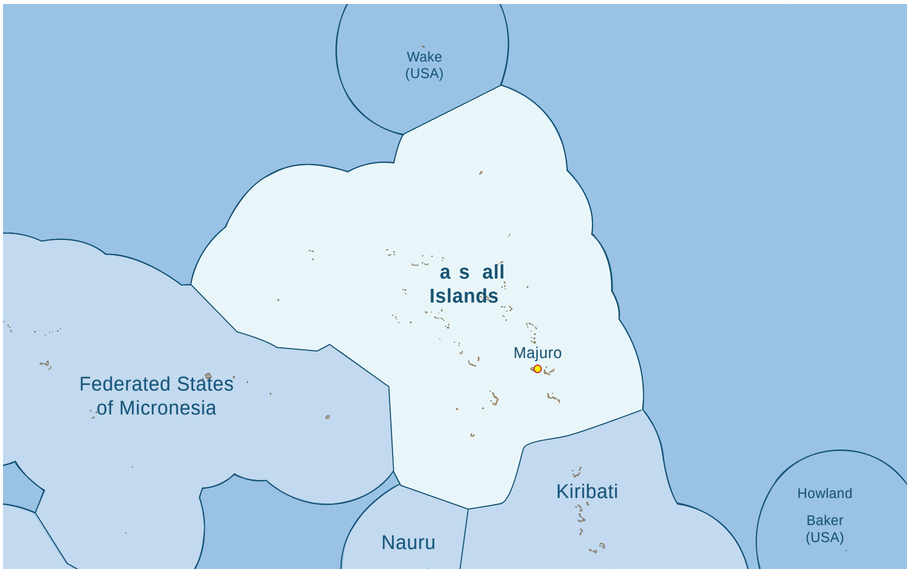
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F2	Foster the care of coastal fish habitats	F1–F3, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.8 Marshall Islands



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	54	63	61	61
Population growth rate[a]	0.7	0.2	-0.2	0

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 2,004,888

Land area (km²) 112

Land as % of EEZ 0.006

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries, with some coastal aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Parties to the Nauru Agreement.

Surface climate and the ocean

Existing features

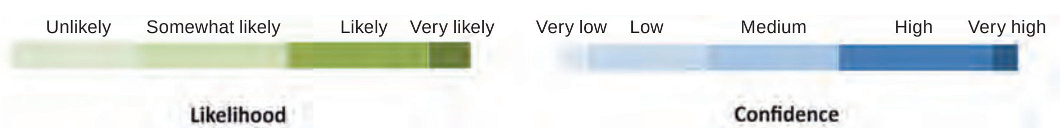
Marshall Islands has a tropical climate {Chapter 2}. Recent air temperatures in Majuro have averaged 27.5°C and average rainfall is ~ 3200 mm per year. Marshall Islands lies within the North Pacific Tropical Gyre Province (NPTG) {Chapter 4, Figure 4.6}. The NPTG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}. As a result, the primary production is very low.

Projected changes to surface climate

Air temperatures and rainfall in Marshall Islands are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.5 (Majuro)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	3238 (Majuro)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	n/a	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Marshall Islands, see www.cawcr.gov.au/projects/PCCSP; n/a = data not available.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Marshall Islands relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the North Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	28.8[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in North Pacific gyre	Continued increase in strength of North Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

Marshall Islands has an industrial purse-seine tuna fishery within its exclusive economic zone (EEZ). Recent average catches (2004–2008) by this fishery have exceeded 47,000 tonnes per year, worth > USD 56.7 million per year. Marshall Islands also licenses foreign fleets to fish for tuna in its EEZ. Recent average annual catches by foreign purse-seine fleets were ~ 22,500 tonnes between 1999 and 2008, worth USD 20 million per year {Chapter 12}. Significant quantities of tuna (> 100,000 tonnes per year) are also landed in Marshall Islands by foreign vessels for transhipping {Chapter 12}. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Purse-seine	47,493	56.2
Longline	98	0.5
Other oceanic fish[a]	33	0.03
Total	**47,624**	**56.73**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The NPTG Province is characterised by low primary production due to the convergence of surface waters and downwelling. Local upwelling near islands can result in enriched surface productivity {Chapter 4, Section 3.2.4}. In general, however, the NTPG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the NPTG Province is projected to increase only slightly and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease significantly in NPTG, particularly by 2100 {Chapter 4, Table 4.3}.

NPTG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+1	+1	+1	+1
Location	Poleward			
Net primary production	-3	-5	-11	-22
Zooplankton biomass	-3	-4	-10	-18

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Marshall Islands are expected to increase by > 20% in 2035 and B1 in 2100, relative to the 20-year average (1980–2000). Catches under A2 in 2100 are projected to increase to a lesser degree due to the increased warming of the Western Central Pacific Ocean. Catches of bigeye tuna are projected to decrease in 2035 and 2100 under both scenarios, with quite significant changes expected under A2 in 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+24	+24	+10	-3	-10	-27

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Marshall Islands are made up of four categories: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 3750 tonnes in 2007, worth > USD 7.2 million. The commercial catch was 950 tonnes. Demersal fish are estimated to make up > 60% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	2417	1080	3	250	3750	7.2
Contribution (%)[a]	64	29	< 1	7	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

Marshall Islands has significant areas of coral reef habitat {Chapter 5} that support many important fisheries species. Small areas of mangroves also occur. The areas of seagrasses and intertidal sand and flats have not been mapped {Chapter 6}.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	13,930	0.03	n/a	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Marshall Islands, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area[c]	-10	-50	-60
Seagrass area[c]	< -5 to -10	-5 to -25	-10 to -30

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs; c = indicative estimates from Federated States of Micronesia {Chapter 6}.

Projected changes in coastal fisheries production

All categories of coastal fisheries in Marshall Islands are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and the indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna contribute to the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relatively heavy reliance on demersal fish and the projected decrease in productivity of all coastal fishery components. As a result, potential catches from coastal fisheries in Marshall Islands are projected to decrease slightly under both scenarios in 2035. By 2100, decreases in coastal fisheries production are projected to be ~ 15% under the B1 scenario and ~ 30% under A2.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	64	-3.5	-2	-20	-13	-35	-22.5
Nearshore pelagic fish	29	0	0	-10	-3	-17.5	-5
Targeted invertebrates	< 1	-3.5	-0.004	-10	-0.01	-20	-0.02
Inter/subtidal invertebrates	7	0	0	-5	-0.3	-10	-0.7
Total catch[a]			**-2**		**-16**		**-28**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Marshall Islands; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Marshall Islands has no freshwater or estuarine fisheries.

Aquaculture

Recent and potential production

The main aquaculture commodities in Marshall Islands are produced in coastal waters for livelihoods. The commodities include black pearls, marine ornamentals (cultured hard and soft corals and giant clam) and trochus. The farming of marine fish is also under development.

Existing and projected environmental features

Increasing SST, rainfall, ocean acidification and possibly stronger storm surge from more severe cyclones are expected to reduce the survival and growth of pearl oyster spat, ornamental products and trochus {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Annual rainfall (mm)	3238[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Cyclones (no. per year)	n/a	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	28.8	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

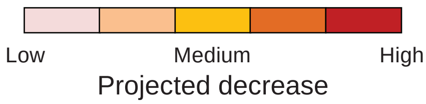
* Approximates A2 in 2050; a = data for Majuro.

Projected changes in aquaculture production

The effects of climate change are eventually expected to have an adverse effect on the existing and potential coastal aquaculture commodities in Marshall Islands {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Existing				
Pearls	Livelihoods			
Marine ornamentals	Livelihoods			
Trochus	Livelihoods			
Potential				
Marine fish	Livelihoods			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The surface fishery for tuna contributed ~ 20%, and the longline fishery contributed 2%, to the gross domestic product (GDP) of Marshall Islands in 2007 {Chapter 12}. Licence fees from foreign purse-seine and longline vessels contributed 2% and 1.2% to government revenue (GR), respectively.

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Surface[a]	32.7	21	2	2
Longline	3.2	2	1.4	1.2

* Information for 2007, when national GDP was USD 156 million (Gillett 2009)[1]; ** information for longline contribution to GR for 2003; a = locally-based purse-seine fleet.

Projected effects of climate change

Preliminary modelling indicates that the contribution of the industrial tuna fishery to GDP in Marshall Islands is projected to increase from ~ 20% to ~ 25% by 2035 and under the B1 scenario in 2100. Smaller increases are projected under A2 in 2100 {Chapter 12}. Minor increases are also expected to government revenue. The projected increases are due to the expected shift to the east in the abundance and distribution of tuna {Chapter 8}.

Projected changes to GDP (%)			Projected changes to GR (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+2 to +6	+2 to +6	+1 to +2	0 to +1	0 to +1	0

* Approximates A2 in 2050.

Food security

Marshall Islands is among the group of PICTs (Group 1) where the estimated sustainable production of fish and invertebrates from coastal habitats will be more than enough to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Marshall Islands is estimated to be 39 kg per person per year[1], just above the recommended level for good nutrition. At present, coral reefs in Marshall Islands are estimated to be able to supply a surplus of > 700 kg of fish per person per year above the recommended level.

Effects of population growth

The demand for fish for food security increases in Marshall Islands due to the predicted growth in population. However, there will still be more than enough fish available from coastal habitats to provide significant surpluses of fish for the remainder of the century.

Variable	2010	2035	2050	2100
Population (x 1000)	54	63	61	61
Fish available per person (kg/year)[a]	768	667	683	685
Surplus (kg/person/year)[b]	733	632	648	650

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The effects of climate change on coastal fisheries in Marshall Islands are not expected to have a significant effect on the fish available for food security per person. The large area of coral reef relative to population size should continue to supply a surplus of coastal fish for food security, even if coastal fish production declines by up to 50% under the A2 scenario in 2100 {Chapter 9}. The improved access to nearshore tuna resources expected to occur as a result of climate change should also provide more fish.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Livelihoods

Current contributions

Large numbers of full-time and part-time jobs have been created through tuna processing in Marshall Islands, and there is also a small number of jobs on tuna vessels. Coastal fisheries also provide > 50% of households in rural communities with either their first or second source of income.

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	**2006**	**2008**	**2002**	**2006**	**2008**	**1st**	**2nd**	**Both**	**2007**
5	0	25	457	100	116	36	18	54	5

* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

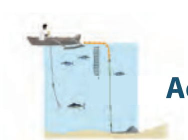
Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and coastal aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario			
	Oceanic fisheries**	Coastal fisheries		Aquaculture (coastal)
		Nearshore pelagic fish	Other resources	
Present*	⇧	⇧	⇩	⇧
2035	↑	No effect	↓	↓
2050	↑	↓	↓	↓
2100	↓	↓	↓	↓

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches.

Percentage increase Percentage decrease



Adaptations and suggested policies

The plans Marshall Islands has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. secure access to the tuna required for industrial fishing and processing operations;

2. manage coastal fish habitats and fish stocks to ensure the continued supply of fish for food security; and
3. increase the number of livelihoods that can be based on fishing, tourism and coastal aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E1	Full implementation of sustainable fishing effort schemes	E1, E2, E4–E6
E2	Diversify sources of fish for processing	E1–E5
E3	Immediate conservation management measures for bigeye tuna	E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E6	Gender-sensitive fish processing operations	
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

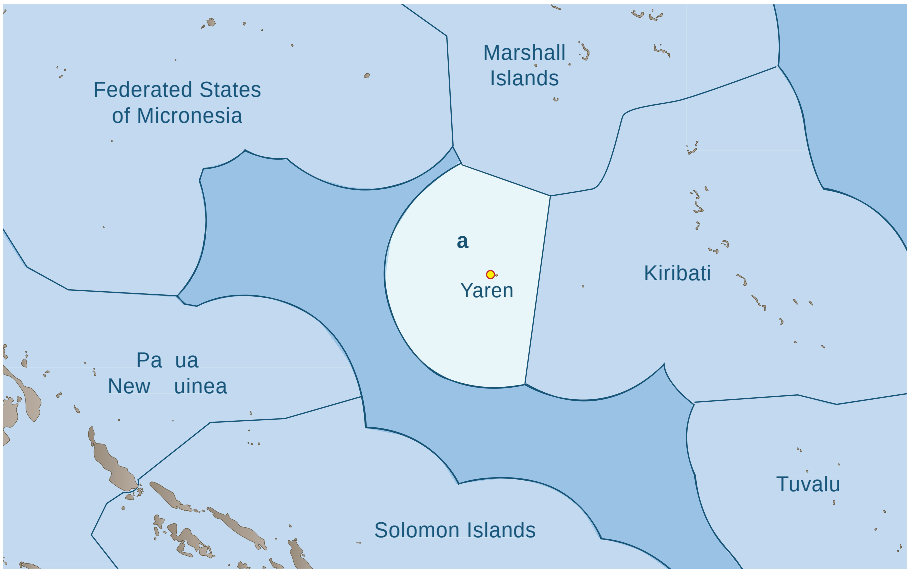
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F2	Foster the care of coastal fish habitats	F1–F3, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F8	Increase access to tuna for urban and rural populations	F8–F13, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	**Summary of adaptation**	**Supporting policy no. (Section 3.7)**
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.9 Nauru



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	10	14	16	21
Population growth rate[a]	2.1	1.2	0.8	0.2

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 293,079

Land area (km²) 21

Land as % of EEZ 0.007

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries, with some pond aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Parties to the Nauru Agreement.

Surface climate and the ocean

Existing features

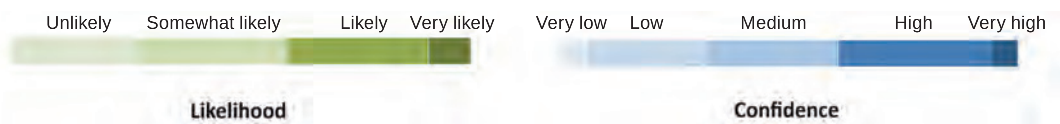
Nauru has a tropical climate {Chapter 2}. Recent air temperatures in Yaren have averaged 27.9°C and average rainfall is ~ 1950 mm per year. Nauru lies within the Pacific Equatorial Divergence (PEQD) and the Western Pacific Warm Pool (Warm Pool) provinces depending on the prevailing El Niño-Southern Oscillation (ENSO) conditions {Chapter 4, Section 4.3}. The PEQD Province is generated by the effects of the earth's rotation on the South Equatorial Current, which results in significant upwelling of nutrients {Chapter 4, Figure 4.3}. These conditions create the richest surface waters in the region.

Projected changes to surface climate

Air temperatures and rainfall in Nauru are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.9 (Yaren)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1948 (Yaren)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			

* Approximates A2 in 2050; a = for more detailed projections of rainfall and air temperature in the vicinity of Nauru, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Nauru relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents, such as the Southern Equatorial Current, and the area and location of PEQD, the Warm Pool and their convergence, are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	29.3[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	SEC decreases at equator; EUC becomes shallower; SECC decreases and retracts westward			
Warm Pool area (x 10^6 km^2)[b]	7	+230% (20–26)	+250% (22–27)	+480% (36–46)	+770% (48–65)
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset; b = Warm Pool defined as area with temperature above 29°C; SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current.

Oceanic fisheries

Recent catch and value

Nauru has only a very small local fishery for tuna within its exclusive economic zone (EEZ). Recent average catches (2004–2008) were 1.2 tonnes per year, worth USD 4500. In contrast, foreign fleets licensed to fish in Nauru's EEZ made average annual catches of 63,000 tonnes between 1999 and 2008, worth USD 52 million. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Longline	0.6	3100
Other methods	0.6	1400
Total	**1.2**	**4500**

* Calculated using market value per tonne for 2004–2008.

Existing oceanic fish habitat

The PEQD Province is characterised by high-salinity, nutrient-rich waters, and an abundance of phytoplankton {Chapter 4, Figure 4.7}. However, primary production in PEQD is limited by low iron concentrations {Chapter 4, Figure 4.9}. The convergence of PEQD and the Warm Pool creates prime feeding areas for tuna {Chapters 4 and 8}. Changes in the position of this convergence zone due to the El Niño-Southern Oscillation have a major influence on the abundance of tuna in the EEZ of Nauru.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the Warm Pool Province is projected to expand, the area of PEQD is projected to contract and the convergence zone with the Warm Pool is expected to move eastward. There are likely to be only minor changes in the key components of the food web for tuna (net primary production and zooplankton biomass) in PEQD, but decreases of up to 10% by 2100 are projected for the Warm Pool {Chapter 4}.

Province feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
PEQD surface area[a]	-20	-27	-30	-50
Warm Pool surface area[a]	+18	+21	+26	+48
Location of convergence	Eastwards			
PEQD net primary production	0	0	+2	+4
PEQD zooplankton biomass	-2	-2	-3	-6
Warm Pool net primary production	-7	-5	-9	-9
Warm Pool zooplankton biomass	-6	-3	-9	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}; PEQD = Pacific Equatorial Divergence; Warm Pool = Western Pacific Warm Pool.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Nauru are projected to increase by 20–25% in 2035 and B1 in 2100, relative to the 20-year average (1980–2000). However, catches are expected to approximate the 20-year average under A2 in 2100. Catches of bigeye tuna are projected to decrease under both scenarios in 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+25	+20	-1	-1	-7	-19

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Nauru are made up mainly of three categories: demersal fish (bottom-dwelling fish associated with coral reef habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 650 tonnes in 2007, worth > USD 1.5 million. The commercial catch was 200 tonnes. Demersal and nearshore pelagic fish are estimated to make equally important contributions to total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	310	310	0	30	650	1.5
Contribution (%)[a]	48	48	0	4	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by tuna species.

Existing coastal fish habitat

Nauru has only 7 km^2 of coral reef habitat {Chapter 5} to support coastal fisheries species.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	7	0.01	0	0

a = Includes mainly fringing reefs {Chapter 5}; b = values from Chapter 6, Table 6.1.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs in Nauru, resulting in declines in this important habitat {Chapters 5 and 6}.

Habitat feature	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[a]	-25 to -65	-50 to -75	> -90

* Approximates A2 in 2050; a = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

All categories of coastal fisheries in Nauru are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the projected decrease in productivity of all components. As a result, total catches from coastal fisheries in Nauru are projected to decrease slightly under both scenarios in 2035 and continue to decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	48	-3.5	-2	-20	-9	-35	-17
Nearshore pelagic fish	48	0	0	-10	-5	-17.5	-8
Inter/subtidal invertebrates	4	0	0	-5	-0.2	-10	-0.4
Total catch[a]			**-2**		**-14**		**-25.4**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Nauru; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Nauru has no freshwater or estuarine fisheries.

Aquaculture

Recent and potential production

The main aquaculture commodity in Nauru is milkfish, which is produced in freshwater ponds. There is limited potential to culture Nile tilapia in ponds to increase access to fish for food security.

Existing and projected environmental features

Higher rainfall and air temperatures are expected to improve the conditions for pond aquaculture of milkfish and tilapia in Nauru {Chapter 11}.

Environmental feature	1980–1999 average[a]	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.9	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1948	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%

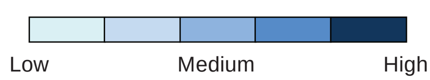
* Approximates A2 in 2050; a = data for Yaren.

Projected changes in aquaculture production

The projected effects of climate change on pond aquaculture in Nauru are expected to be positive, with enhanced production due to increased rainfall and warmer temperatures {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Existing				
Milkfish	Food security			
Potential				
Tilapia	Food security			

* Approximates A2 in 2050.



Projected increase

Economic and social implications

Economic development and government revenue

Current contributions

The surface fishery by foreign purse-seine vessels in the EEZ of Nauru does not contribute to gross domestic product (GDP). However, licence fees from these fleets contributed 20% to government revenue (GR) in Nauru in 2007.

Industrial fishery	Contribution to GDP		Contribution to GR*	
	USD m	GDP (%)	USD m	GR (%)
Surface	0	0	6.1	20

* Information for 2007, when total GR was USD 30 million (Gillett 2009)[1].

Projected effects of climate change

The contribution of the surface tuna fishery in Nauru's EEZ to government revenue is projected to increase due to the effects of climate change on the distribution and abundance of tuna. Under both scenarios in 2035, and under B1 in 2100 (A2 in 2050), the contributions of licence fees to government revenue are projected to increase from 20% to ~ 25% {Chapter 12}.

Projected changes to GR (%)		
B1/A2 2035	B1 2100*	A2 2100
+2 to +6	+2 to +5	0

* Approximates A2 in 2050.

Food security

Nauru is among the group of PICTs (Group 3) where the estimated sustainable production of fish and invertebrates from coastal habitats is unable to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Nauru is estimated to be 56 kg per person per year[2], well above the recommended level for good nutrition. Much of this fish comes from tuna and other large species caught close to the coast, and from imported canned fish.

Fish consumption per person (kg)	Animal protein from fish (%)	Fish provided by subsistence catch (%)
56	71	66

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Effects of population growth

Predicted population growth in Nauru will have little effect on the gap between the fish estimated to be available per person from coral reefs and the fish needed for nutrition because this gap is already very wide.

Variable	2010	2035	2050	2100
Population (x 1000)	10	14	16	21
Fish available per person (kg/year)[a]	2	1	1	1
Gap (kg/person/year)[b]	33	34	34	34

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

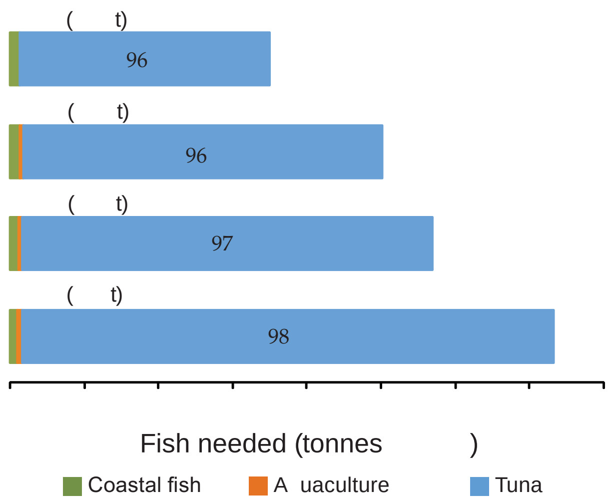
Additional effects of climate change

The projected decreases in productivity of demersal fish related to climate change {Chapter 9} are not expected to widen the gap.

Filling the gap

Tuna (and other large pelagic fish) are the only resources available to Nauru that can supply the shortfall in fish from coral reefs for food because pond aquaculture is only expected to provide minor quantities of fish.

The implication is that Nauru needs to allocate a proportion of the annual average tuna catch taken from its EEZ to provide the quantities of fish recommended for good nutrition of their population that cannot be met by purchases of imported canned fish.



Fish (in tonnes) needed for future food security in Nauru, and the recommended contributions (%) of fisheries resources and aquaculture production required to meet future needs.

Livelihoods

Current contributions

Only small numbers of jobs have been created through tuna fishing in Nauru {Chapter 12}. Coastal fisheries provide 22% of households with either their first or second source of income.

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
5	0	0	10	2	0	5	17	22	n/a

Information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project; n/a = data not available.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from the nearshore component of coastal fisheries and pond aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario		
	Coastal fisheries		Aquaculture (ponds)
	Nearshore pelagic fish	Other resources	
Present*	⇧	⇩	⇧
2035	No effect	⬇	⬆
2050	⬇	⬇	⬆
2100	⬇	⬇	⬆

* Indicates general direction of new opportunities for livelihoods based on the activity.

Percentage increase | Percentage decrease

Adaptations and suggested policies

The plans Nauru has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. improve access to tuna to provide fish for government revenue and continued food security;

2. manage coastal fish habitats and fish stocks to optimise the use of coastal fisheries for food security; and
3. enhance sustainable livelihood opportunities in the fisheries and aquaculture sector through capacity building.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E1	Full implementation of sustainable fishing effort schemes	E1, E2, E4–E6
E3	Immediate conservation management measures for bigeye tuna	E8
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

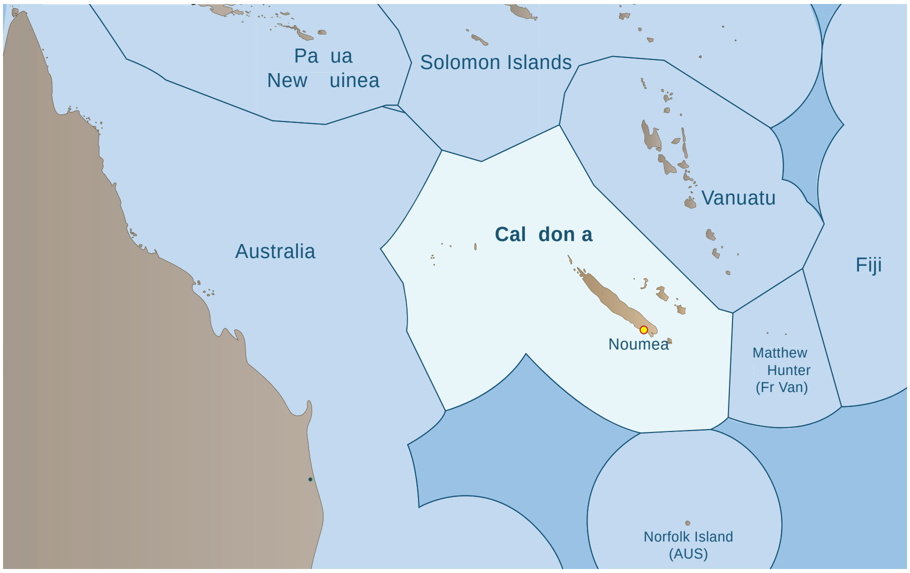
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F2	Foster the care of coastal fish habitats	F1–F3, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F8	Increase access to tuna	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	F13–16, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2

2.10 New Caledonia



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	252	323	343	372
Population growth rate[a]	1.3	0.7	0.3	0

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 1,111,900

Land area (km²) 19,100

Land as % of EEZ 1.7

Fisheries and aquaculture activities: Oceanic fisheries, coastal fisheries, freshwater and estuarine fisheries, and coastal aquaculture.

Membership of regional fisheries management arrangements: Western and Central Pacific Fisheries Convention (participating territory); Melanesian Spearhead Group.

Surface climate and the ocean

Existing features

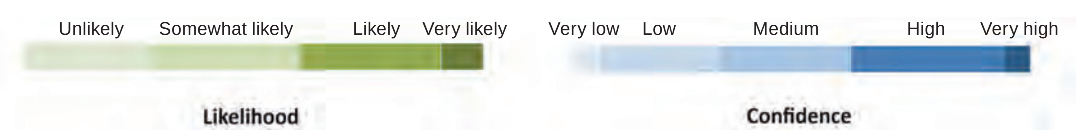
New Caledonia has a tropical-subtropical climate {Chapter 2}. Recent air temperatures in Noumea have averaged 23.5°C and average rainfall is ~ 1050 mm per year. New Caledonia lies within the Archipelagic Deep Basins Province (ARCH) {Chapter 4, Figure 4.6}. The climate and ocean within this province are influenced by a complex current regime caused by the occurrence of many islands, archipelagos and seamounts. These formations divert oceanic circulation to create eddies, resulting in upwelling, downwelling and other mesoscale processes {Chapter 3, Section 3.2.9, Figure 3.1}. ARCH Province is characterised by a patchwork of nutrient-rich and nutrient-poor water bodies that can vary over short timeframes.

Projected changes to surface climate

Air temperatures in New Caledonia are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}. Rainfall is expected to decrease overall, with reductions occurring during winter and increases during summer.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	23.5 (Noumea)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1066 (Noumea)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	2.3	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the southern subtropical Pacific, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding New Caledonia relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	25.1[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents****	Increase in South Pacific gyre	SEC decreases at equator; EUC becomes shallower; SECC decreases and retracts westward			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; **** applies mainly to the area 0°–10°S north of New Caledonia; a = average for EEZ derived from the HadISST dataset; SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current

Oceanic fisheries

Recent catch and value

New Caledonia has a small longline fishery within its exclusive economic zone (EEZ). Recent average catches (2004–2008) by this fishery have been > 2140 tonnes per year, worth ~ USD 10.4 million. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Longline	1975	10.2
Other oceanic fish[a]	167	0.2
Total	**2142**	**10.4**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The waters surrounding New Caledonia within ARCH are influenced by eddies and other mesoscale processes (boundary currents, jets, wind-driven upwelling, internal waves and tidal mixing) created by the way landmasses divert surface currents

{Chapter 4, Section 4.3.4}. These mesoscale processes commonly bring nutrients to surface waters and result in a variable mosaic of feeding areas for tuna and other large pelagic fish {Chapter 3, Section 3.2.9}.

Projected changes to oceanic fish habitat

The area of the ARCH Province remains the same by definition. However, key components of the food web (net primary production and the biomass of zooplankton) are expected to decrease significantly under the B1 and A2 scenarios by 2100 in ARCH {Chapter 4, Table 4.3}.

ARCH feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Net primary production	-5	-8	-20	-33
Zooplankton biomass	-5	-6	-17	-26

* Approximates A2 in 2050.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 scenarios, catches of skipjack tuna in the EEZ of New Caledonia are expected to increase in 2035 and 2100, relative to the 20-year average (1980–2000). This increase is particularly significant under A2 in 2100. Catches of bigeye tuna are projected to remain relatively stable under both scenarios in 2035 and B1 in 2100, and to increase slightly under A2 in 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward .

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+22	+19	+39	+1	+1	+6

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of New Caledonia are made up of four categories: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, Spanish mackerel, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 4850 tonnes in 2007, worth > USD 24.5 million. The commercial catch was 1350 tonnes. Demersal fish are estimated to make up 55% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	2670	560	300	1320	4850	24.5
Contribution (%)[a]	55	12	6	27	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

New Caledonia has ~ 36,000 km^2, the largest area estimated for any Pacific Island country and territory of coral reef habitat {Chapter 5}. There are also significant areas of mangroves, deepwater and intertidal seagrasses, and intertidal sand and mud flats {Chapter 6}. These habitats support many important fisheries species.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	35,925	205	936	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in New Caledonia, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	-5 to -10	-5 to -20	-10 to -25

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

All categories of coastal fisheries in New Caledonia are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = non-tuna species dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relatively heavy reliance on demersal fish and the projected decrease in productivity of all components of coastal fisheries. As a result, potential catches from coastal fisheries in New Caledonia are likely to decrease slightly under both scenarios in 2035. By 2100, declines are expected to be more substantial, particularly under the A2 scenario.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	55	-3.5	-2	-20	-11	-35	-19
Nearshore pelagic fish	12	0	0	-10	-1	-17.5	-2
Targeted invertebrates	6	-3.5	-0.2	-10	-0.6	-20	-1
Inter/subtidal invertebrates	27	0	0	-5	-1	-10	-3
Total catch[a]			**-2**		**-14**		**-25**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in New Caledonia; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in New Caledonia include eels, flagtails (jungle perch), tilapia, tropical snappers (especially mangrove jack), mullet and *Macrobrachium*. These species are mostly taken by subsistence fishers from lowland rivers and lakes. The estimated annual freshwater fish catch in 2007 was 10 tonnes, worth USD 45,800 {Chapter 10}[1]. No data are available on the volume and value of the catch of estuarine species taken by commercial fishers, but some estuarine species appear regularly in the fish market in Noumea.

Existing freshwater and estuarine fish habitat

The larger rivers of New Caledonia provide a range of freshwater and estuarine fish habitats that support fish and invertebrates {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km^2)	River length (km)
Grande Terre	Le Diahot	589	100
Grande Terre	Tontouta	380	38

Projected changes to freshwater and estuarine fish habitat

The projected changes to rainfall patterns in New Caledonia {Chapter 2, Section 2.5.2} are expected to result in greater variability, and possible loss, in the area and quality of all freshwater fish habitats {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	B1 2100*	A2 2100
-5 to +10	-10 to +5	-20 to +20

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Greater variability in rainfall and river flows are expected to result in minimal changes, or even slightly reduced production, from freshwater and estuarine fisheries in New Caledonia by 2100 under both scenarios {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
0 to +2.5	-2.5	0

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

Penaeid shrimp have been produced from coastal habitats in relatively large quantities (~ 2000 tonnes per year) in New Caledonia for many years. Shrimp are the largest agro-food export from New Caledonia, providing valuable employment opportunities in remote rural areas {Chapter 11} and contributing one third of the combined value of production from fisheries and aquaculture. Trials for growing hatchery-reared sea cucumbers (sandfish) in earthen ponds are underway and farming of marine fish (rabbitfish) to supply the local market has also recently commenced.

Aquaculture commodity	Annual production (tonnes)	Annual value (USD million)*
Penaeid shrimp	2000	29

* 2007 data.

Existing and projected environmental features

Many of the features of surface climate and the ocean important to the aquaculture of shrimp, marine fish and sea cucumbers are expected to change in ways that are likely to affect production. Changing rainfall and increasing air and sea temperatures in New Caledonia are likely to affect coastal aquaculture. In addition, sea-level rise is expected to affect the drainage of shrimp ponds, reducing farm profitability {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	23.5[a]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	1066[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Cyclones (no. per year)	2.3	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	25.1	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = data for Noumea.

Projected changes in aquaculture production

Higher air temperatures could enhance shrimp growth in the medium term, and improve survival of shrimp if the existing variability in temperature decreases. However, by 2100 increasing summer temperatures and declining rainfall are likely to reduce growth rates of the blue shrimp presently produced in New Caledonia. Changing rainfall and increasing SST are expected to increase the mortality and incidence of disease in shrimp farms {Chapter 11, Table 11.5}. Sea-level rise is also expected to affect the existing infrastructure of shrimp ponds {Chapter 11, Section 11.3.2.2}.

Production of sandfish and rabbitfish is likely to have a low vulnerability to increasing air temperature and SST, sea level and ocean acidification in 2035. These changes are expected to have increased negative effects on production of these commodities by 2100 {Chapter 11}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Shrimp	Livelihoods	↑	↓	↓
Marine fish	Livelihoods	↓	↓	↓
Sea cucumbers	Livelihoods	↓	↓	↓

* Approximates A2 in 2050.

Low Medium High
Projected increase

Low Medium High
Projected decrease

Economic and social implications

Economic development and government revenue

Current contributions

The locally-based longline fishery makes only very minor contributions to gross domestic product (GDP) due to the large size of New Caledonia's economy and made up only 0.05% of GDP in 2007.

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Surface	0	0	-	-
Longline	1.7	0.05	n/a	n/a

* Information for 2007, when national GDP was USD 8829 million (Gillett 2009)[1]; n/a = data not available.

Projected effects of climate change

Any changes to the contribution of the tuna fishery to GDP due to the projected changes in the distribution and abundance of tuna resulting from climate change are likely to be negligible {Chapter 12}.

Food security

New Caledonia is among the group of PICTs (Group 1) where the estimated sustainable production of fish and invertebrates from coastal habitats will be more than enough to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in New Caledonia is estimated to be 26 kg per person per year[2], below the recommended level for good nutrition. However, fish consumption in rural areas is 55 kg per person per year.

Fish consumption per person (kg)			Fish provided by subsistence catch (%)	
National	**Rural**	**Urban**	**Rural**	**Urban**
26	55	11	91	42

Effects of population growth

New Caledonia will have an increasing total demand for fish for food due to the predicted growth in population. However, the large areas of coral reef are expected to continue to provide a great surplus of fish relative to the catch needed for good nutrition of the population until at least 2100.

Variable	2010	2035	2050	2100
Population (x 1000)	252	323	343	372
Fish available per person (kg/year)[a]	428	334	314	290
Surplus (kg/person/year)[b]	393	299	279	255

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The effects of climate change on coastal fisheries are not expected to cause declines in the fish available per person significant enough to affect food security in New Caledonia. The large area of coral reefs relative to population size will continue to supply a surplus of coastal fish for food security up to 2100 even if the production of coastal fisheries declines by up to 50%.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Livelihoods

Current contributions

Coastal fisheries provide important opportunities to earn income for coastal communities in New Caledonia, with 46% of households in representative coastal communities deriving their first or second income from catching and selling fish. Shrimp farming provides > 550 jobs in rural areas[4]. The numbers of full-time and part-time jobs that have been created by tuna fishing are undetermined.

Coastal households earning income from fishing (%)			Jobs in aquaculture*
1st	2nd	Both	2007
23	23	46	560

* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and coastal aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario			
	Oceanic fisheries**	Coastal fisheries		Aquaculture (coastal)
		Nearshore pelagic fish	Other resources	
Present*	↑	↑	↓	↑
2035	↑	No effect	↓	↓
2050	No effect	↓	↓	↓
2100	↓	↓	↓	↓

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due largely to their subsistence role

Percentage increase　　Percentage decrease

Adaptations and suggested policies

The plans New Caledonia has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. increase access to tuna, and the efficiency of longlining operations;

2. manage coastal fish habitats and fish stocks to ensure these resources continue to provide fish for food security; and
3. increase the number of livelihoods that can be based on fishing, tourism and coastal aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

<table>
<tr><th>Adaptation no. (Section 3.2)</th><th>Summary of adaptation</th><th>Supporting policy no. (Section 3.3)</th></tr>
<tr><td>E3</td><td>Immediate conservation management measures for bigeye tuna</td><td>E8</td></tr>
<tr><td>E4</td><td>Energy efficiency programmes for industrial tuna fleets</td><td rowspan="2">E9</td></tr>
<tr><td>E5</td><td>Environmentally-friendly fishing operations</td></tr>
<tr><td>E7</td><td>Safety at sea</td><td>E10</td></tr>
<tr><td>E8</td><td>Climate-proof infrastructure</td><td>E11</td></tr>
<tr><td>E9</td><td>Pan-Pacific tuna management</td><td>E2</td></tr>
</table>

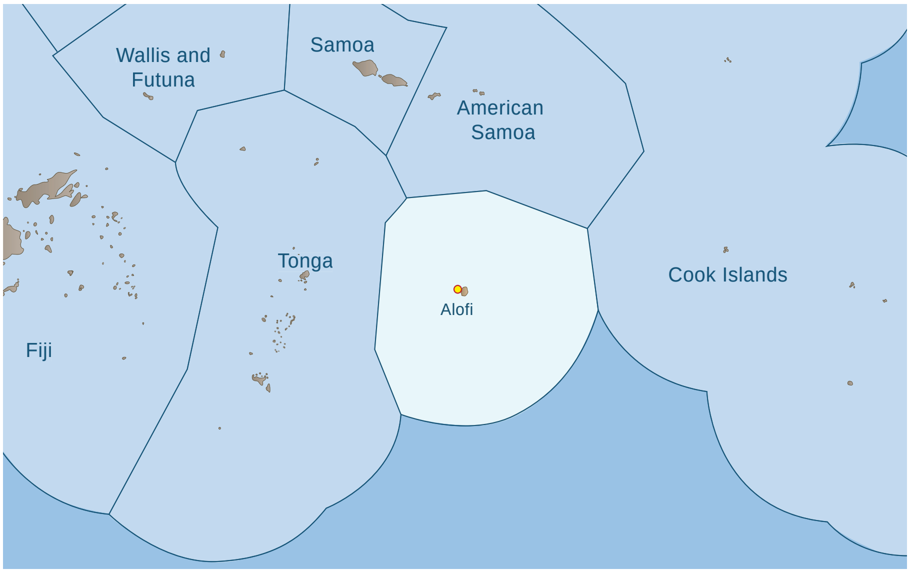
Food security

<table>
<tr><th>Adaptation no. (Section 3.4)</th><th>Summary of adaptation</th><th>Supporting policy no. (Section 3.5)</th></tr>
<tr><td>F1</td><td>Manage and restore vegetation in catchments</td><td>F1, F2, F18</td></tr>
<tr><td>F2</td><td>Foster the care of coastal fish habitats</td><td>F1–F3, F18</td></tr>
<tr><td>F3</td><td>Provide for landward migration of coastal fish habitats</td><td>F4, F5, F18</td></tr>
<tr><td>F4</td><td>Allow for expansion of freshwater habitats</td><td>F4, F18</td></tr>
<tr><td>F5</td><td>Sustain production of coastal demersal fish and invertebrates</td><td>F6, F7, F13, F18</td></tr>
<tr><td>F6</td><td>Diversify catches of coastal demersal fish</td><td rowspan="2">F6, F13, F18</td></tr>
<tr><td>F7</td><td>Manage freshwater and estuarine fisheries to harness opportunities</td></tr>
</table>

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.11 Niue



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	1.5	1.2	1.2	1.2
Population growth rate[a]	-2.3	-0.7	0.2	n/a

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp); n/a = data not available.

EEZ area (km²) 296,941

Land area (km²) 259

Land as % of EEZ 0.087

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Te Vaka Moana Arrangement; South Pacific Tuna and Billfish subcommittee.

Surface climate and the ocean

Existing features

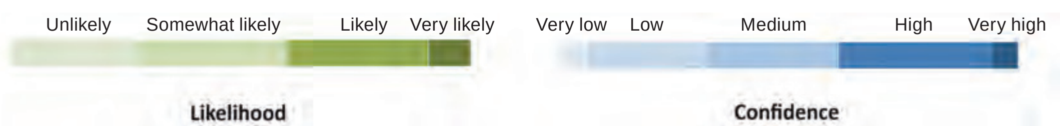
Niue has a tropical climate {Chapter 2}. Recent air temperatures in Hanan have averaged 24.3°C and average annual rainfall is ~ 1950 mm per year. Niue lies within the South Pacific Subtropical Gyre Province (SPSG) {Chapter 4, Figure 4.6}. The SPSG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}.

Projected changes to surface climate

Air temperatures and rainfall in Niue are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	24.3 (Hanan)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1958 (Hanan)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	1.6	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Niue, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Niue relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	26.3[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

Niue has had a small longline fishery within its exclusive economic zone (EEZ), which produced annual average catch of 130 tonnes, worth > USD 630,000. This fishery has now ceased. Little fishing is done by foreign fleets in Niue's EEZ – average annual catches between 1999 and 2008 were < 20 tonnes. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD)* 2004–2008
Tuna		
Longline	120	618,500
Other methods	2	4180
Other oceanic fish[a]	8	8400
Total	**130**	**631,080**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

Niue's EEZ lies within the generally nutrient-poor waters of the SPSG Province {Chapter 4, Figure 4.6}. This province is characterised by downwelling and low nitrate concentrations in deeper waters. Net primary production is low, particularly in summer when there is the formation of a marked thermocline {Chapter 4, Section 4.4.3}. Local upwelling around islands can result in small areas of enriched surface productivity. In general, however, the SPSG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the SPSG Province is projected to increase and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease in SPSG {Chapter 4, Table 4.3}.

SPSG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+4	+7	+7	+14
Location	Poleward extension of southern limit			
Net primary production	-3	-5	-3	-6
Zooplankton biomass	-3	-4	-5	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of bigeye tuna in the EEZ of Niue are expected to decrease in 2035 and 2100, relative to the 20-year average (1980–2000). No estimates are available for catches of skipjack tuna {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress.

Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100
-5	-8	-15

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Niue are made up mainly of three components: demersal fish (bottom-dwelling fish associated with coral reef habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 150 tonnes in 2007, worth > USD 676,000. The commercial catch was 10 tonnes. Nearshore pelagic fish are estimated to make up 50% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	62	75	0	13	150	0.7
Contribution (%)[a]	41	50	0	9	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

Niue has 56 km^2 of coral reefs within its EEZ that support coastal fisheries species. Niue has no other coastal habitats due to the steep slope of the coastline and narrow fringing reef.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reef habitats in Niue, resulting in declines in coral cover in both the medium and long term {Chapter 5}.

Habitat feature	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[a]	-25 to -65	-50 to -75	> -90

* Approximates A2 in 2050; a = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish and intertidal and subtidal invertebrates in Niue are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna form part of the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the importance of nearshore pelagic fish and the projected increase in productivity of this component of the fishery. As a result, total catches from coastal fisheries in Niue are projected to increase under both scenarios in 2035 and increase slightly under B1 in 2100. Greater projected reductions in catches of demersal fish are expected to cause a decline in coastal fisheries production of ~ 10% by 2100 under the A2 emissions scenario.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	41	-3.5	< 2	-20	-8	-35	-14
Nearshore pelagic fish	50	+17.5	+9	+20	+10	+10	+5
Inter/subtidal invertebrates	9	0	0	-5	< 1	-10	-1
Total catch[a]			**+7**		**+1**		**-10**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Niue; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Niue has no freshwater or estuarine fisheries.

Aquaculture

Niue has no aquaculture production.

Economic and social implications

Economic development and government revenue

Current contributions

The longline tuna fishery contributed 3.7% to the gross domestic product (GDP) of Niue in 2007 {Chapter 12}. Licence fees from foreign purse-seine vessels have contributed up to 2.2% of government revenue (GR) in some years {Chapter 12}.

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Longline	0.4	3.7	0.03	0.2

* Information for 2007, when national GDP was USD 10 million (Gillett 2009)[1]; ** information for 1999.

Projected effects of climate change

Changes to GDP and GR due to the effects of climate change on the distribution and abundance of tuna are likely to be difficult to project due to the difficulty in operating locally-based fleets and the relatively small size of Niue's EEZ.

Food security

Niue is among the group of PICTs (Group 2) where the estimated sustainable production of fish and invertebrates from coastal habitats has the potential to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i]. However, it may be difficult to distribute the catch to the island due to the distance of some of the coral reef habitat from the shore {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Niue is estimated to be 79 kg per person per year[2], significantly more than the recommended level for good nutrition. At present, coral reefs in Niue are estimated to be able to supply a surplus of 77 kg of fish above the recommended level.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Effects of population growth

The population of Niue is predicted to decline in the short term and then remain relatively stable from 2035 onwards. Therefore, demand for fish for food security is not expected to increase. The current estimated fish surplus per person per year is estimated to increase in the years ahead.

Variable	2010	2035	2050	2100
Population	1500	1200	1300	1300
Fish available per person (kg/year)[a]	112	140	129	129
Surplus (kg/person/year)[b]	77	105	94	94

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The effects of climate change on coastal fisheries are not expected to significantly affect the fish available per person for food security in Niue. The large area of coral reefs relative to population size will continue to supply sufficient coastal fish for food security even with the expected decline in the productivity of demersal fish {Chapter 12}.

Livelihoods

Current contributions

Small numbers of full-time and part-time jobs have been created through tuna fishing and processing in Niue. Coastal fisheries provide limited opportunities to earn income for coastal communities presumably due to the large subsistence catch.

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)		
2002	2006	2008	2002	2006	2008	1st	2nd	Both
5	0	0	0	14	18	1	9	10

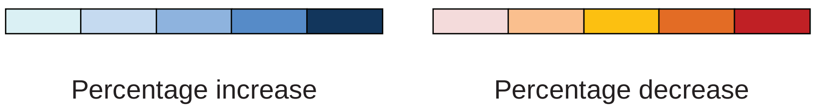
* Information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries and the nearshore component of coastal fisheries. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario		
	Oceanic fisheries**	Coastal fisheries	
		Nearshore pelagic fish	Other resources
Present*	⇧	⇧	⇩
2035	⬆	No effect	⬇
2050	No effect	⬇	⬇
2100	⬇	⬇	⬇

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches.



Adaptations and suggested policies

The plans Niue has to derive greater socio-economic benefits from fisheries will depend on interventions to:

1. improve access to tuna to provide fish for economic development and continued food security;
2. manage coastal fish habitats and fish stocks to ensure the future supply of fish for food security; and
3. enhance livelihood opportunities based on fishing and tourism.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E3	Immediate conservation management measures for bigeye tuna	E8
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

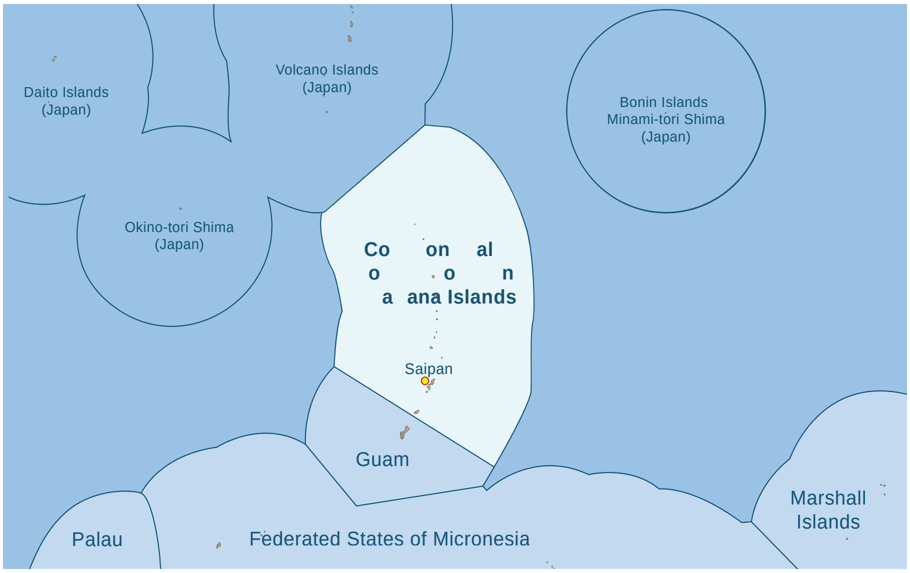
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F2	Foster the care of coastal fish habitats	F1–F3, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L3	Develop coral reef ecotourism ventures	L3

2.12 Commonwealth of the Northern Mariana Islands



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	63	76	80	87
Population growth rate[a]	-0.1	0.6	0.3	0

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 752,922

Land area (km²) 478

Land as % of EEZ 0.06

Fisheries and aquaculture activities: Oceanic fisheries, coastal fisheries and coastal aquaculture.

Membership of regional fisheries management arrangements: Western Pacific Regional Fisheries Management Council; Western and Central Pacific Fisheries Commission (participating territory).

Surface climate and the ocean

Existing features

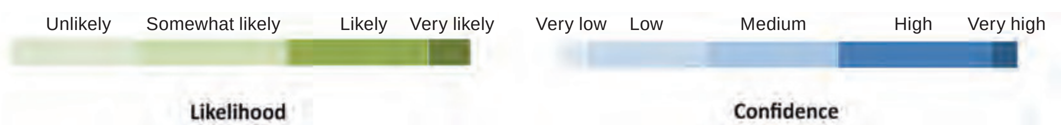
Commonwealth of the Northern Mariana Islands (CNMI) has a tropical climate {Chapter 2}. Recent air temperatures have averaged 27.4°C and average rainfall is 1840 mm per year. CNMI lies within the North Pacific Tropical Gyre Province (NPTG) {Chapter 4, Figure 4.6}. The NPTG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}. As a result, the primary production is very low.

Projected changes to surface climate

Air temperatures and rainfall in CNMI are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.4	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1840	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	n/a	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of CNMI, see www.cawcr.gov.au/projects/PCCSP; n/a = data not available.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding CNMI relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the North Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	28.1[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in North Pacific gyre	Continued increase in strength of North Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

CNMI has a small fishery based on trolling for skipjack and yellowfin tuna within its exclusive economic zone (EEZ). Recent average catches (2004–2008) by this fishery were 112 tonnes per year, worth > USD 260,000. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD)* 2004–2008
Tuna		
Troll	112	260,300
Other oceanic fish[a]	1	800
Total	**113**	**261,100**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The NPTG Province is characterised by low primary production due to the convergence of surface waters and downwelling. Local upwelling near islands can result in enriched surface productivity {Chapter 4, Section 3.2.4}. In general, however, the NTPG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the NPTG Province is projected to increase only slightly and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease significantly in NPTG, particularly by 2100 {Chapter 4, Table 4.3}.

NTPG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+1	+1	+1	+1
Location	Poleward			
Net primary production	-3	-5	-11	-22
Zooplankton biomass	-3	-4	-10	-18

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 scenarios in 2035 and B1 in 2100, catches of skipjack tuna in the EEZ of CNMI are expected to increase by > 20%, relative to the 20-year average (1980–2000), and by > 10% under A2 in 2100. Catches of bigeye tuna are projected to remain unchanged in 2035 and decrease in 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+23	+22	+13	0	-5	-23

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of CNMI are made up mainly of three categories: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be ~ 450 tonnes in 2007, worth > USD 1.6 million. The commercial catch was ~ 230 tonnes. Demersal fish are estimated to make up ~ 60% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	260	161	0	30	451	1.6
Contribution (%)[a]	58	35	0	7	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

CNMI has a relatively small area of coral reef {Chapter 5}, mangroves, seagrasses, and intertidal flats {Chapter 6} to support coastal fisheries species.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	250	0.07	6.7	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in CNMI, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-30	-70	-80
Seagrass area	< -5 to -10	-5 to -25	-10 to -35

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

All coastal fisheries in CNMI are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = non-tuna species dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relatively high reliance on demersal fish and the projected decrease in the productivity of all coastal fishery components. As a result, total catches from coastal fisheries in CNMI are projected to decrease under both scenarios in 2035 and 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	58	-3.5	-2	-20	-11.5	-35	-20
Nearshore pelagic fish	35	0	0	-10	-3.6	-17.5	-6.3
Inter/subtidal invertebrates	7	0	0	-5	-0.4	-10	-0.7
Total catch[a]			**-2**		**-15.5**		**-27**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in CNMI; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

CNMI has no freshwater or estuarine fisheries.

Aquaculture

Recent and potential production

The main aquaculture commodities in CNMI are shrimp and marine fish. These species are grown in coastal waters. Pond aquaculture trials to produce tilapia for food security have also been carried out.

Existing and projected environmental features

Increasing SST, rainfall, sea level and ocean acidification, and possibly stronger storm surge from more severe cyclones, are expected to have negative effects on the conditions required to culture shrimp and marine fish {Chapter 11}.

Environmental feature	**1980–1999 average**	**Projected change**			
		B1 2035	**A2 2035**	**B1 2100***	**A2 2100**
Air temperature (°C)	27.4	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	1840	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Cyclones (no. per year)	n/a	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	28.1	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140

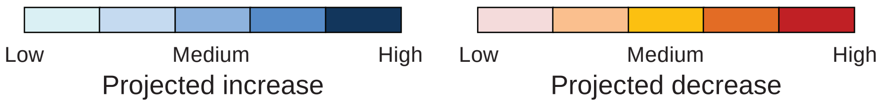
* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; n/a = data not available.

Projected changes in aquaculture production

The projected effects of climate change in CNMI are eventually expected to have adverse effects on the production of coastal aquaculture commodities {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Existing				
Shrimp	Livelihoods			
Marine fish	Livelihoods			
Potential				
Tilapia	Food security			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The tuna fishery in CNMI is small and does not contribute noticeably to gross domestic product (GDP) or government revenue (GR) {Chapter 12}.

Projected effects of climate change

Any changes to the contribution of the tuna fishery to GDP and GR due to the projected changes in the distribution and abundance of tuna resulting from climate change are likely to be negligible {Chapter 12}.

Food security

CNMI is among the group of PICTs (Group 3) where the estimated sustainable production of fish from coastal habitats is unable to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Subsistence fish consumption data are not available for CNMI. All calculations of the fish needed for food security in this summary are based on the recommended 35 kg of fish per person per year[1].

Effects of population growth

CNMI will have an increasing demand for fish for food security due to the predicted growth in population. The large existing shortfall of 23 kg per person per year

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public health Programme (SPC 2008)[25].

between the estimated sustainable production of fish from coral reefs and the fish needed for good nutrition is expected to increase to 25 kg in 2035, and 26 kg in 2050 and 2100, due to population growth.

Variable	2010	2035	2050	2100
Population (x 1000)	63	76	80	87
Fish available per person (kg/year)[a]	12	10	9	9
Gap (kg/person/year)[b]	23	25	26	26

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

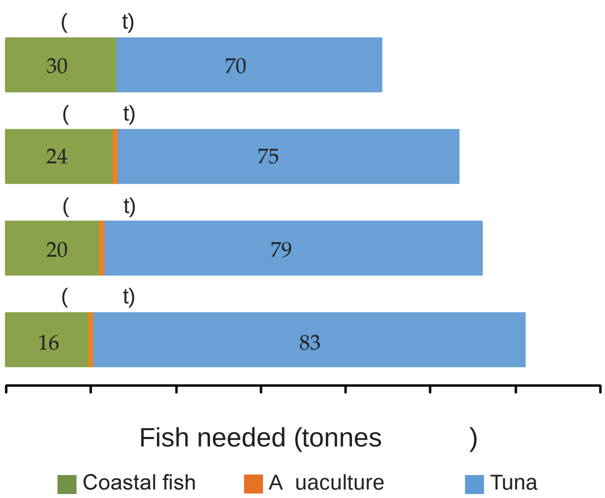
Additional effects of climate change

CNMI faces further declines in the fish available per person due to the combined effects of population growth and the effects of climate change on coastal fisheries production. By 2050, climate change is projected to cause the gap between the fish needed per person for good nutrition and the fish available from coral reefs to increase from 26 to 27 kg per person per year. In 2100, this gap is expected to increase from 26 to 29 kg.

Filling the gap

Tuna is the main resource available to CNMI to supply the shortfall in fish from coral reefs and other coastal habitats for food because there are limited opportunities for expansion of aquaculture. The role of tuna in food security is important now and becomes increasingly important over time as the gap widens in 2050 and 2100.

The implication is that CNMI should plan to increase access to fresh and canned tuna to provide the quantities of fish recommended for good nutrition of their population.



Fish (in tonnes) needed for future food security in CNMI, and the recommended contributions (%) of fisheries resources and aquaculture production to meet future needs.

Livelihoods

Current contributions

The number of full-time and part-time jobs on tuna vessels in CNMI is undetermined, and no data exist for income earned by coastal households from fishing. There are 12 jobs in aquaculture in CNMI[4].

Projected effects of climate change

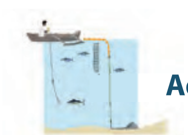
The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario				
	Oceanic fisheries**	Coastal fisheries		Aquaculture	
		Nearshore pelagic fish	Other resources	Ponds	Coastal
Present*	⇧	⇧	⇩	⇧	⇧
2035	↑	No effect	↓	↑	↓
2050	No effect	↓	↓	↑	↓
2100	↓	↓	↓	↑	↓

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches.

Percentage increase

Percentage decrease



Adaptations and suggested policies

The plans CNMI has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. maximise access to tuna, and the efficiency of tuna fishing operations, to provide fish for economic development and food security;
2. manage coastal fish habitats and fish stocks to maximise the contribution of coastal fisheries to food security; and

3. increase the number of livelihoods that can be based on fishing, tourism and aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E3	Immediate conservation management measures for bigeye tuna	E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

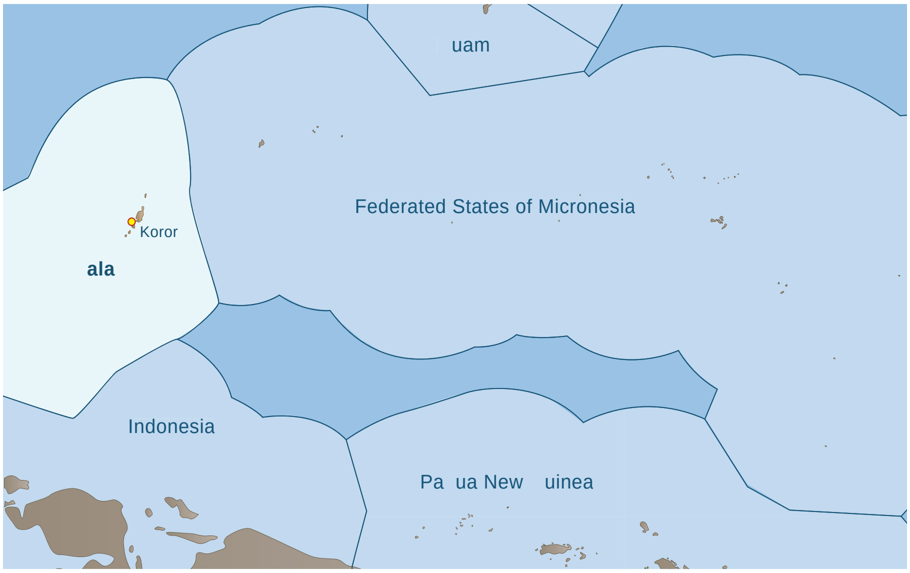
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	F13–16, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.13 Palau



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	21	22	22	22
Population growth rate[a]	0.6	0.2	-0.1	0

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km^2) 605,506

Land area (km^2) 494

Land as % of EEZ 0.082

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries, with some freshwater and estuarine fisheries and coastal aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Parties to the Nauru Agreement.

Surface climate and the ocean

Existing features

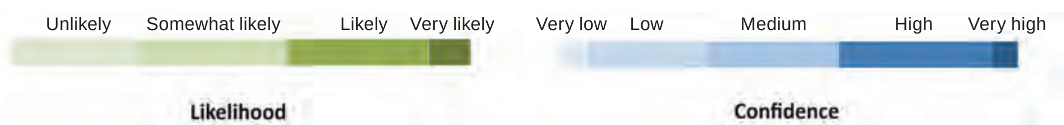
Palau has a tropical climate {Chapter 2}. Recent air temperatures in Koror have averaged 27.8°C and average rainfall is > 3700 mm per year. Palau lies within the Western Pacific Warm Pool (Warm Pool) {Chapter 4, Figure 4.6}. The primary influence on surface climate in the Warm Pool is the El Niño-Southern Oscillation (ENSO), which also affects the surrounding ocean. Under normal conditions the net primary production (NPP) in this part of the ocean is low due to the deep thermocline. However, NPP increases during El-Niño episodes because the thermocline becomes shallower.

Projected changes to surface climate

Air temperatures and rainfall in Palau are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.8 (Koror)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	3710 (Koror)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			

* Approximates A2 in 2050; a = for more detailed projections of rainfall and air temperature in the vicinity of Palau, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Palau relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the North Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	28.9[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in North Pacific gyre	Continued increase in strength of North Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

Palau has a small longline fishery for tuna within its exclusive economic zone (EEZ). Recent average catches (2004–2008) have been < 10 tonnes per year, worth ~ USD 36,000. Palau also licenses foreign fleets to fish in its EEZ. Between 1999 and 2008, the annual average catch of foreign purse-seine fleets was 1815 tonnes, worth > USD 1.8 million, and the catch of foreign longline fleets averaged 2380 tonnes, worth USD 12 million. Foreign longline vessels also land an average of > 3000 tonnes of tuna in Palau each year for air freight to destinations in Asia. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD)* 2004–2008
Tuna		
Longline	7	36,260
Total	**7**	**36,260**

* Calculated using market value per tonne for 2004–2008.

Existing oceanic fish habitat

The Warm Pool is generally poor in nutrients, although net primary production increases during El Niño events when the depth of the thermocline decreases, bringing more nutrient-rich waters within the photic zone {Chapter 4, Section 4.3.2}.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the Warm Pool is projected to expand {Chapter 4, Table 4.3}. The greater stratification of the water column in the Warm Pool due to higher sea surface temperature {Chapter 3}, and the increased depth of the nutricline {Chapter 4}, are projected to reduce net primary production within the EEZ of Palau.

Warm Pool feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+18	+21	+26	+48
Location	Eastwards			
Net primary production	-7	-5	-9	-9
Zooplankton biomass	-6	-3	-9	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 scenarios, catches of skipjack tuna in the EEZ of Palau are expected to increase in 2035, relative to the 20-year average (1980–2000). However, by 2100 only small increases in catch are likely to occur under B1 and catches are expected to decline under A2. Catches of bigeye tuna are projected to decrease under both scenarios in 2035 and 2100, and significantly under A2 in 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+10	+2	-27	-4	-11	-45

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Palau are made up of four components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 2115 tonnes in 2007, worth > USD 5.4 million. The commercial catch was 865 tonnes. Demersal fish are estimated to make up 45% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	950	680	100	385	2115	5.4
Contribution (%)[a]	45	32	5	18	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

Palau has ~ 2500 km^2 of coral reef {Chapter 5}, as well as smaller areas of mangroves, deepwater and intertidal seagrasses, and intertidal sand and mud flats {Chapter 6} that support many fisheries species.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	2496	47	80	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Palau, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	< -5 to -10	-5 to -25	-10 to -35

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

All components of coastal fisheries in Palau are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the projected decreases in productivity of all components of the fishery. As a result, potential catches from coastal fisheries in Palau are projected to decrease slightly under both scenarios in 2035, and to continue to decline until 2100, particularly under the A2 scenario.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	45	-3.5	-1.6	-20	-9	-35	-16
Nearshore pelagic fish	32	0	0	-10	-3	-17.5	-15
Targeted invertebrates	5	-3.5	-0.2	-10	-0.5	-20	-1
Inter/subtidal invertebrates	18	0	0	-5	-1	-10	-2
Total catch[a]			**-2**		**-14**		**-24**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Palau; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in Palau are eels and *Macrobrachium*. These species are mostly harvested for subsistence. The estimated annual freshwater fish catch in 2007 was 1 tonne, worth USD 8000 {Chapter 10}[1].

Existing freshwater and estuarine fish habitat

The rivers in Palau provide a limited range of freshwater and estuarine fish habitats and have moderately diverse fish communities {Chapter 7, Section 7.2.5.6}.

Island	Largest river	Catchment area (km^2)	River length (km)
Babeldaob	Ngerdorch	39	15

Projected changes to freshwater and estuarine fish habitat

The higher projected rainfall for Palau {Chapter 2, Section 2.5.2} is expected to result in increases in the area and quality of freshwater fish habitats {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	B1 2100*	A2 2100
-5 to +5	-5 to +10	-5 to +20

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

The projected increases in rainfall and river flow are expected to slightly improve the production from freshwater and estuarine fisheries by 2100 in Palau. River flow increases the availability and quality of habitats, provides cues for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
0	+2.5	+7.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

Aquaculture commodities produced for livelihoods in the coastal waters of Palau include trochus and marine ornamentals (giant clam). Palau is also producing ~ 70 tonnes of milkfish per year for good and investigating production of small quantities of cultured milkfish juveniles for bait for tuna longlining. Hatchery production of marine fish (coral trout) and sea cucumbers is also under development.

Existing and projected environmental features

Increasing SST, rainfall and ocean acidification are eventually expected to reduce the survival and growth of ornamental products, trochus, marine fish and sea cucumbers {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.8[a]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	3710[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Sea surface temperature (°C)	28.9	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

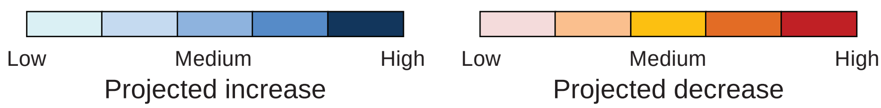
* Approximates A2 in 2050; a = data for Koror.

Projected changes in aquaculture production

Production of aquaculture commodities in coastal waters is likely to be affected negatively by the changing climate but milkfish farming in ponds is expected to be favoured by higher air temperatures and rainfall {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Milkfish	Food security	↑	↑	↑
Marine ornamentals	Livelihoods	↓	↓	↓
Marine fish	Livelihoods	↓	↓	↓
Sea cucumbers	Livelihoods	↓	↓	↓
Trochus	Livelihoods	↓	↓	↓

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The local and foreign longline fisheries contributed 3.4% to the gross domestic product (GDP) of Palau in 2007 {Chapter 12}. Licence fees from foreign vessels in the surface and longline fisheries contributed 3.2% and 0.5%, respectively, to government revenue (GR).

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Surface	0	0	1.1	3.1
Longline	5.5	3.4	0.5	0.5

* Information for 2007, when national GDP was USD 157 million (Gillett 2009)[1]; ** information for 2003.

Projected effects of climate change

The projected changes to GR due to the effects of climate change on the distribution and abundance of skipjack tuna are relatively minor due to the small contribution of the surface fishery to the economy of Palau {Chapter 12}.

Projected changes to GR (%)		
B1/A2 2035	**B1 2100***	**A2 2100**
+0.2 to +0.3	0 to +0.1	-0.7 to -0.9

* Approximates A2 in 2050.

Food security

Palau is among the group of PICTs (Group 1) where the estimated sustainable production of fish and invertebrates from coastal habitats will be more than enough to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Palau is estimated to be 33 kg per person per year[2], close to the recommended level. In rural areas, fish supply ~ 60% of dietary animal protein and 60% of the fish is taken by subsistence fishing. At present, coral reefs in Palau are estimated to be able to supply a surplus of 330 kg of fish per person per year above the recommended 35 kg.

Fish consumption per person (kg)			Animal protein from fish (%)		Fish provided by subsistence catch (%)	
National	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**
33	43	28	59	47	60	35

Effects of population growth

Palau is expected to have a relatively stable population over the 21st century and demand for fish for food security is not likely to change much. The existing estimated fish surplus is expected to be ~ 300 kg per person per year in 2035 and 2100.

Variable	2010	2035	2050	2100
Population (x 1000)	21	22	22	22
Fish available per person (kg/year)[a]	365	330	333	340
Surplus (kg/person/year)[b]	330	295	298	305

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

Although the effects of climate change are expected to reduce the productivity of coastal fisheries, the large area of coral reefs relative to population size should continue to supply a large surplus of coastal fish for food security for the remainder of the century.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public health Programme (SPC 2008)[25].

Livelihoods

Current contributions

Small numbers of full-time and part-time jobs have been created through tuna processing in Palau, but these jobs represent only a low percentage of total employment in the nation. Coastal fisheries provide coastal communities in Palau with opportunities to earn income and 26% of representative coastal households derive their first or second source of income from catching and selling fish.

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
1	0	0	11	5	20	10	16	26	5

* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and coastal aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario			
	Oceanic fisheries**	Coastal fisheries		Aquaculture
		Nearshore pelagic fish	Other resources	(coastal)
Present*	⇧	⇧	⇩	⇧
2035	⬆	No effect	⬇	⬇
2050	No effect	⬇	⬇	⬇
2100	⬇	⬇	⬇	⬇

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due to their subsistence role.

Percentage increase   Percentage decrease

Adaptations and suggested policies

The plans Palau has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. maximise access to tuna, and the efficiency of tuna fishing operations, to provide fish for economic development and continued food security;
2. manage coastal fish habitats and fish stocks to ensure that these resources continue to supply fish for food security; and
3. increase the number of livelihoods that can be based on fishing, tourism and coastal aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

<table>
<tr><th>Adaptation no. (Section 3.2)</th><th>Summary of adaptation</th><th>Supporting policy no. (Section 3.3)</th></tr>
<tr><td>E1</td><td>Full implementation of sustainable fishing effort schemes</td><td>E1, E2, E4–E6</td></tr>
<tr><td>E3</td><td>Immediate conservation management measures for bigeye tuna</td><td>E8</td></tr>
<tr><td>E4</td><td>Energy efficiency programmes for industrial tuna fleets</td><td rowspan="2">E9</td></tr>
<tr><td>E5</td><td>Environmentally-friendly fishing operations</td></tr>
<tr><td>E7</td><td>Safety at sea</td><td>E10</td></tr>
<tr><td>E8</td><td>Climate-proof infrastructure</td><td>E11</td></tr>
<tr><td>E9</td><td>Pan-Pacific tuna management</td><td>E2</td></tr>
</table>

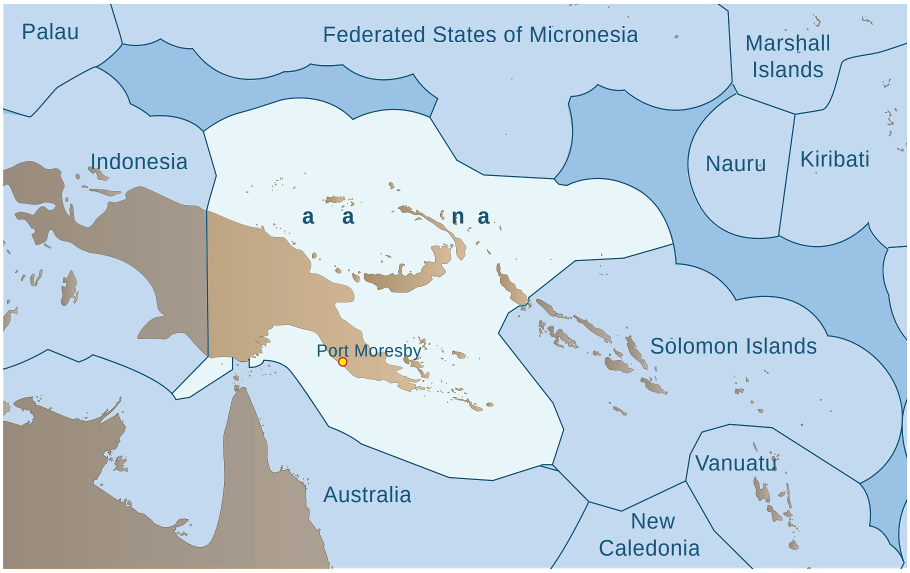
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F4	Allow for expansion of freshwater habitats	F4, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	**Summary of adaptation**	**Supporting policy no. (Section 3.7)**
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.14 Papua New Guinea



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	6753	10,822	13,271	21,125
Population growth rate[a]	2.1	1.5	1.2	0.6

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 2,446,757

Land area (km²) 462,243

Land as % of EEZ 15.9

Fisheries and aquaculture activities: Oceanic fisheries, coastal fisheries, freshwater and estuarine fisheries, freshwater aquaculture and coastal aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Parties to the Nauru Agreement; South Pacific Tuna and Billfish subcommittee; Melanesian Spearhead Group.

Surface climate and the ocean

Existing features

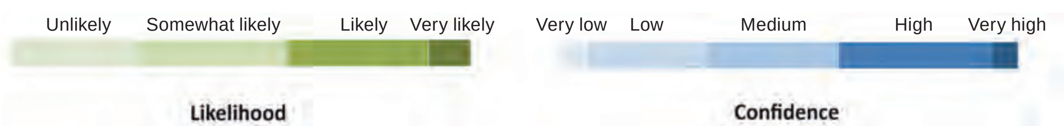
Papua New Guinea (PNG) has a tropical climate {Chapter 2}. Recent air temperatures in Port Moresby have averaged 27.3°C and average rainfall there is > 1100 mm per year (but much higher elsewhere in the country). PNG lies mainly within the Western Pacific Warm Pool Province (Warm Pool) with some southern islands within the Archipelagic Deep Basins Province (ARCH) {Chapter 4, Section 4.3}. The primary influences on the climate and ocean around PNG are the South Pacific Convergence Zone {Chapter 2, Section 2.3.1, Figure 2.4} and South Equatorial Current {Chapter 3, Section 3.2.8, Figure 3.1}.

Projected changes to surface climate

Air temperatures and rainfall in PNG are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.3 (Port Moresby)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1122 (Port Moresby)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			

* Approximates A2 in 2050; a = for more detailed projections of rainfall and air temperature in the vicinity of Papua New Guinea, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding PNG relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents, such as the South Equatorial Current, and the area of the Warm Pool are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	28.7[b]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	SEC decreases at equator; EUC becomes shallower; SECC decreases and retracts westward			
Warm Pool area (x 10^6 km^2)[a]	7	+230% (20–26)	+250% (22–27)	+480% (36–46)	+770% (48–65)
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = Warm Pool defined as area with temperature above 29°C; b = average for EEZ derived from the HadISST dataset; SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current.

Oceanic fisheries

Recent catch and value

PNG has an important, locally-based, industrial fishery within its exclusive economic zone (EEZ), mainly based on purse-seining for tuna. Recent average catches by this fishery (2004–2008) have exceeded 225,000 tonnes per year, worth > USD 280 million. PNG also licenses foreign purse-seine vessels to fish for tuna in its EEZ. The recent average annual catch by these foreign vessels averaged > 220,000 tonnes between 1999 and 2008, worth > USD 200 million {Chapter 12}. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Purse-seine	222,260	263.2
Longline	3690	19.1
Other oceanic fish[a]	345	0.3
Total	**226,295**	**282.6**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The Warm Pool is generally poor in nutrients. However, net primary production increases during El Niño events when the depth of the thermocline decreases, bringing more nutrient-rich waters within the photic zone {Chapter 4, Section 4.3.2}. The convergence of the Warm Pool and the Pacific Equatorial Divergence provinces creates prime feeding areas for tuna {Chapters 4 and 8}. Changes in the position of this convergence zone influence the abundance of tuna in the EEZ of PNG {Chapter 8}. The eastward extension of the Warm Pool during El Niño, and westward contraction during La Niña, changes habitat conditions for tuna in the western Pacific.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the Warm Pool is projected to expand {Chapter 4, Table 4.3}. The greater stratification of the water column in the Warm Pool due to higher sea surface temperature {Chapter 3}, and the increased depth of the nutricline {Chapter 4}, are projected to reduce net primary production within the EEZ of PNG. Relocation of the convergence zone between the Warm Pool and PEQD to the east is also expected to increase the distance between the EEZ of PNG and the prime feeding grounds for tuna {Chapter 8}.

Warm Pool feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+18	+21	+26	+48
Location	Eastwards			
Net primary production	-7	-5	-9	-9
Zooplankton biomass	-6	-3	-9	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ and archipelagic waters of PNG are expected to remain much the same in 2035, relative to the 20-year average (1980–2000). By 2100, catches of skipjack tuna are projected to decrease by ~ 30% under the A2 scenario as these tuna move to the east. Catches of bigeye tuna are projected to follow a similar trend {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+3	-11	-30	-4	-13	-28

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of PNG are made up of four components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, Spanish mackerel, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 35,700 tonnes in 2007, worth USD 62.5 million. The commercial catch was 5700 tonnes. Demersal fish and nearshore pelagic fish are both estimated to make up ~ 40% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	14,520	13,760	1300	6120	35,700	62.5
Contribution (%)[a]	41	38	4	17	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

PNG has very significant areas of coral reefs {Chapter 5}, mangroves, deepwater and intertidal seagrasses, and intertidal sand and mud flats {Chapter 6} that support many important fisheries species.

Habitat	Coral reef[*,a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	22,200	4640	117	n/a

* Approximate estimate only; a = includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in PNG, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	-5 to -20	-5 to -30	-10 to -35

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

All components of coastal fisheries in PNG are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna comprise a part of the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the reliance on demersal fish and nearshore pelagic fish. As a result, total catches from coastal fisheries in PNG are projected to decrease slightly under both scenarios in 2035. However, catches are expected to decline by > 10% in 2100 under the B1 scenario and by > 20% under A2.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	41	-3.5	-1	-20	-8	-35	-14
Nearshore pelagic fish	38	0	0	-10	-4	-17.5	-7
Targeted invertebrates	4	-3.5	-0.1	-10	-0.4	-20	-0.7
Inter/subtidal invertebrates	17	0	0	-5	-0.9	-10	-2
Total catch[a]			**-1.6**		**-13**		**-23**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in PNG; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

PNG has significant freshwater and estuarine fisheries {Chapter 10}. The main species caught are barramundi, river herring, Papuan black bass, fork-tailed catfish, saratoga, tilapia, carp, rainbow trout and *Macrobrachium*. These species are harvested by commercial, artisanal, subsistence and recreational fisheries {Chapter 10}. The estimated freshwater fish catch in 2007 was 17,500 tonnes, worth USD 16.6 million[1].

Existing freshwater and estuarine fish habitat

PNG is the largest continental land mass in the region. The larger rivers and lakes in PNG provide a great diversity of freshwater and estuarine fish habitats. The Fly River floodplain covers an area of > 40,000 km^2.

Largest river/Lake	Catchment area (km^2)	River length (km)
Sepik-Ramu	96,000	1126
Fly	76,000	1050
Purari	33,700	470
Murray	647[a]	-
Kutubu	50[a]	-

a = Actual surface area of lake.

Projected changes to freshwater and estuarine fish habitat

The projected increase in rainfall for PNG {Chapter 2, Section 2.5.2} is expected to result in increases in the area and quality of all freshwater fish habitats, particularly later in the century {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	**B1 2100***	**A2 2100**
-5 to +10	-5 to +20	-5 to +20

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Higher projected rainfall and river flows are expected to result in slightly improved fisheries production from freshwater and estuarine fisheries in PNG by 2035, and increases of up to 7.5% by 2100. River flow increases the availability and quality of habitats, provides cues for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
0 to +2.5	+7.5	+7.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

Pond aquaculture of tilapia and carp is growing rapidly to produce fish for the large inland population of PNG. Recent estimates indicate that > 10,000 small ponds have been constructed. Coastal aquaculture commodities in PNG include shrimp, white pearls produced from the silver- or gold-lipped pearl oyster, seaweed and hatchery-based marine fish (mainly barramundi).

Existing and projected environmental features

Higher rainfall and air temperatures are expected to have positive effects on pond aquaculture and minimal effects on shrimp farming in PNG. However, increasing SST, rainfall and ocean acidification are eventually expected to reduce survival and growth of pearl oyster spat and larval marine fish {Chapter 11}. Production of seaweed is also expected to be affected adversely by higher temperatures and rainfall.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.3[a]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	1122[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Sea surface temperature (°C)	28.7	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

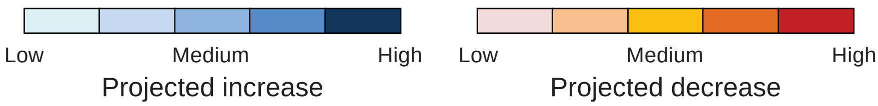
* Approximates A2 in 2050; a = data for Port Moresby.

Projected changes in aquaculture production

The projected effects of climate change on aquaculture in PNG are mixed. Pond aquaculture is expected to be enhanced by increased rainfall, river flows, and warmer temperatures, provided ponds are located where they will not be affected by floods or storm surge. The commodities grown in coastal waters are likely to be affected adversely by increases in SST, rainfall and ocean acidification {Chapter 11, Table 11.5}. However, shrimp farms in PNG should be able to retain their potential to produce 2000 tonnes per year in the medium term.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Tilapia and carp	Food security			
Pearls	Livelihoods			
Seaweed	Livelihoods			
Shrimp	Livelihoods			
Marine fish	Livelihoods			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The locally-based, industrial surface tuna fishery contributed 2.8% to the gross domestic product (GDP) of PNG in 2007 {Chapter 12}. The longline fishery contributed 0.03% to GDP. When the value of post-harvest processing of tuna in canneries is added to fishing operations, the contribution to GDP increases. Licence fees from foreign vessels (and national vessels) involved in the surface fishery contributed 0.6% to government revenue (GR) in 2007.

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Surface[a]	161	2.8	15	0.6
Longline	2.7	0.03	0	0

* Information for 2007, when national GDP was USD 5708 million (Gillett 2009)[1]; ** information for 2007, when total GR was USD 2599 million; a = locally-based purse-seine and pole-and-line fleets.

Projected effects of climate change

The projected changes to the contributions to GDP and GR derived from the surface fishery due to the effects of climate change on the distribution and abundance of skipjack tuna are expected to be relatively minor because the PNG economy is large {Chapter 12, Table 12.9}.

Projected changes to GDP (%)**			Projected changes to GR (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
0 to +0.1	-0.2 to -0.4	-0.4 to -1.2	0	0 to -0.1	-0.1 to -0.2

* Approximates A2 in 2050; ** information for 2007, when total GDP was USD 5708 million and GR was USD 2559 million (Gillet 2009)[1].

Food security

PNG is among the group of PICTs (Group 3) where the estimated sustainable production of fish and invertebrates from coastal and freshwater habitats is unable to supply the national population with the amount of fish needed per person per year for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in PNG is estimated to be 13 kg per person per year[2], well below the recommended levels for good nutrition. This is primarily due to the fact that much of the large inland population of PNG does not have good access to fish. At present, coastal and freshwater habitats in PNG are estimated to be able to supply only 12 kg of fish per person per year.

Fish consumption per person (kg)			Fish provided by subsistence catch (%)	
National	Rural	Urban	Rural	Urban
13	10	28	64	n/a

n/a = Data not available.

Effects of population growth

PNG will have a rapidly increasing total demand for fish for food security due to the predicted growth of its population. The current estimated shortfall of fish below the recommended level is 23 kg per person per year. This shortfall is expected to increase to 27 kg per person per year in 2035, 29 kg in 2050 and 31 kg in 2100.

Variable	2010	2035	2050	2100
Population (x 1000)	6753	10,822	13,271	21,125
Fish available per person (kg/year)[a]	12	8	6	4
Gap (kg/person/year)[b]	23	27	29	31

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

Climate change is expected to cause only relatively minor additional declines in the fish available per person from coastal fisheries. For example, by 2100 under the

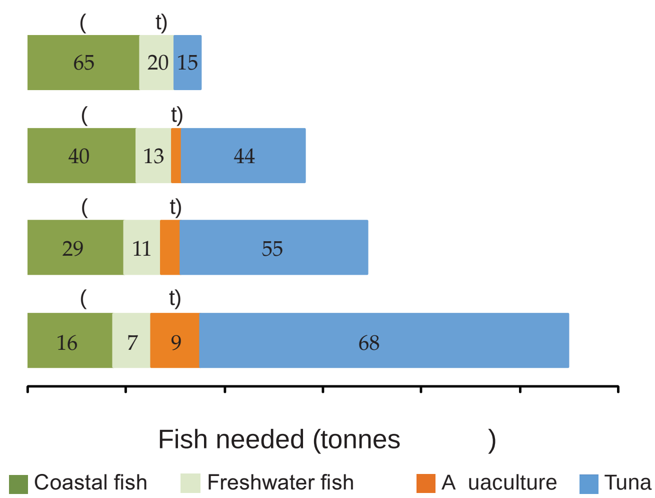
i For most Pacific Island countries and territories, this is based on 35 kg of fish per person per year contributing 50% of dietary protein as recommended by the SPC Public Health Programme, although it is acknowledged that this target is not practical for PNG due to poor access to fish by inland populations (SPC 2008)[25].

A2 emissions scenario, the direct and indirect effects of climate change on coastal fisheries are projected to cause the gap between the fish needed per person for good nutrition, and the fish available from coral reefs, to increase from 31 to 32 kg per person per year.

Filling the gap

Increased access to tuna, and development of small pond aquaculture and freshwater fisheries, all have potential to help supply the shortfall in fish from coastal habitats for food security in PNG. However, this gap will need to be filled mainly by tuna because freshwater fisheries and pond aquaculture are only expected to be able to provide relatively limited quantities of fish. The role of tuna becomes increasingly important in 2050 and 2100. Freshwater fisheries and pond aquaculture will make their greatest contributions in those inland areas where even access to canned tuna is difficult.

The implication is that an increasing proportion of the annual average tuna catch will need to be allocated over time to provide the quantities of fish recommended for good nutrition of PNG's population. The proportions of the total amount of fish needed for food security to be contributed by tuna reach 44% in 2035, 55% in 2050, and 68% in 2100.



Fish (in tonnes) needed for future food security in PNG, and the recommended contributions (%) of fisheries resources and aquaculture production to meet future needs.

These estimates are based on maintaining recent average consumption of 13 kg per person per year instead of the 35 kg per person per year recommended for other Pacific Island countries and territories.

Livelihoods

Current contributions

Large numbers of full-time and part-time jobs have been created through tuna fishing and processing in PNG, although they represent only a low percentage of total employment in the nation due to the large population. Coastal fisheries also provide important opportunities to earn income for coastal communities throughout the country – in representative coastal communities 86% of households are estimated to derive their first or second income from catching and selling fish. Aquaculture has created > 10,000 jobs[4].

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
460	110	440	2707	4000	8550	53	32	86	> 10,000

* Mainly represents potential opportunities to earn income from sale of fish produced in freshwater ponds; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries, freshwater fisheries, and pond and coastal aquaculture. The A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario					
	Oceanic fisheries**	Coastal fisheries		Freshwater fisheries	Aquaculture	
		Nearshore pelagic fish	Other resources		Ponds	Coastal
Present*	⇧	⇧	⇩	⇧	⇧	⇧
2035	↑	No effect	↓	↑	↑	↓
2050	No effect	↓	↓	↑	↑	↓
2100	↓	↓	↓	↑	↑	↓

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches.

Percentage increase

Percentage decrease

Adaptations and suggested policies

The plans PNG has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. secure access to the tuna required for canneries and improve the efficiency of locally-based industrial fleets;
2. increase access to tuna to provide the fish needed for food security for both rural and urban communities, and
3. increase the number of livelihoods that can be based on fishing and processing tuna, the nearshore pelagic fish component of coastal fisheries, and aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

<table>
<tr><th>Adaptation no. (Section 3.2)</th><th>Summary of adaptation</th><th>Supporting policy no. (Section 3.3)</th></tr>
<tr><td>E1</td><td>Full implementation of sustainable fishing effort schemes</td><td>E1, E2, E4–E6</td></tr>
<tr><td>E2</td><td>Diversify sources of fish for canneries</td><td>E1–E5, E7</td></tr>
<tr><td>E3</td><td>Immediate conservation management measures for bigeye tuna</td><td>E7, E8</td></tr>
<tr><td>E4</td><td>Energy efficiency programmes for industrial tuna fleets</td><td rowspan="3">E9</td></tr>
<tr><td>E5</td><td>Environmentally-friendly fishing operations</td></tr>
<tr><td>E6</td><td>Gender-sensitive fish processing operations</td></tr>
<tr><td>E7</td><td>Safety at sea</td><td>E10</td></tr>
<tr><td>E8</td><td>Climate-proof infrastructure</td><td>E11</td></tr>
<tr><td>E9</td><td>Pan-Pacific tuna management</td><td>E2</td></tr>
</table>

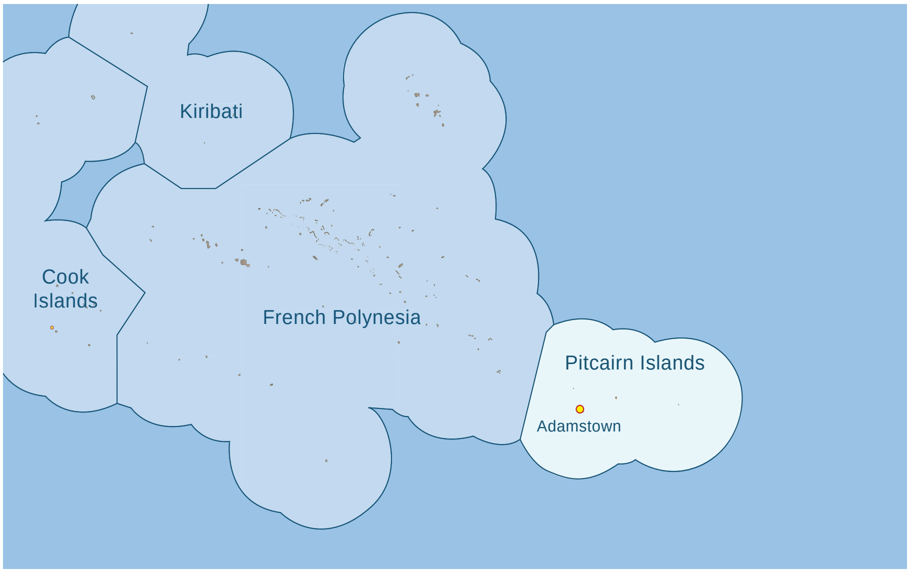
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F4	Allow for expansion of freshwater habitats	F4, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F7	Manage freshwater and estuarine fisheries to harness opportunities	
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	F13–16, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.15 Pitcairn Islands



Key features

Population

Year	2010	2035	2050	2100
Population[a]	66	66	66	66
Population growth rate[a]	n/a	n/a	n/a	n/a

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp); n/a = data not available.

EEZ area (km²) 800,000

Land area (km²) 5

Land as % of EEZ 0.001

Fisheries and aquaculture activities: Coastal fisheries.

Membership of regional fisheries management arrangements: Pitcairn Islands is not a member of any regional fisheries management organisation.

Surface climate and the ocean

Existing features

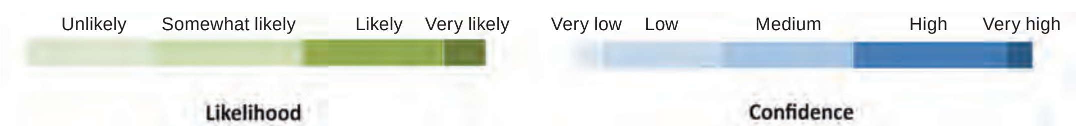
Pitcairn Islands has a tropical climate {Chapter 2}. Recent air temperatures in Adamstown have averaged 20.9°C and average rainfall is ~ 1500 mm per year. Pitcairn Islands lies within the South Pacific Subtropical Gyre Province (SPSG) {Chapter 4, Figure 4.6}. The SPSG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}.

Projected changes to surface climate

Air temperatures in Pitcairn Islands are projected to increase and rainfall is expected to decrease in the southern subtropical Pacific due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average[b]	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	20.9 (Adamstown)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1512 (Adamstown)	+5 to +10%	-5 to -20%	-5 to -20%	-5 to -20%
		More extreme wet and dry periods			

* Approximates A2 in 2050; a = for more detailed projections of rainfall and air temperature in the subtropical Pacific, see www.cawcr.gov.au/projects/PCCSP; b = 1960–1999 data for Adamstown.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Pitcairn Islands relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	24.2[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

There is no fishing activity in the exclusive economic zone of Pitcairn Islands by locally-based vessels, and little or no fishing by foreign fleets in recent years.

Coastal fisheries

Recent catch and value

The coastal fisheries of Pitcairn Islands are made up mainly of three components: demersal fish (bottom-dwelling fish associated with the coast and coral reef habitats), nearshore pelagic fish, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 12 tonnes in 2007, worth > USD 70,000. The commercial catch was 5 tonnes. Demersal fish are estimated to make up > 80% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	10	1	0	1	12	0.07
Contribution (%)[a]	84	8	0	8	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}.

Existing coastal fish habitat

Pitcairn Islands has 48 km^2 of coral reef habitat that supports coastal fisheries species. There are no mangrove or seagrass habitats. The area of intertidal sand flats on outlying reefs has not been documented.

Projected changes to coastal fish habitat

Increasing sea surface temperatures and ocean acidification are expected to affect the health of coral reefs in Pitcairn Islands, in the medium and long term {Chapter 5}. In particular, coral cover is projected to decrease over time.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish and intertidal and subtidal invertebrates in Pitcairn Islands are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. There is the possibility that tuna may eventually increase as the distributions and abundances of the main species change {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish	+15 to +20	+20	+10	Changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050.

The overall projected change to coastal fisheries catch reflects the relative reliance on demersal fish and the projected decrease in productivity of this component of the fishery. As a result, potential catches from coastal fisheries in Pitcairn Islands are projected to decrease slightly under both scenarios in 2035 and continue to decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	84	-3.5	-3	-20	-17	-35	-29
Nearshore pelagic fish	8	+17.5	+1	+20	+2	+10	+0.8
Inter/subtidal invertebrates	8	0	0	-5	-0.4	-10	-0.8
Total catch[a]			**-1.5**		**-15**		**-29**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Pitcairn Islands; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Pitcairn Islands has no freshwater or estuarine fisheries.

Aquaculture

Pitcairn Islands has no aquaculture production.

Economic and social implications

Economic development and government revenue

Licence fees from foreign vessels do not contribute to government revenue in Pitcairn Islands.

Food security

Pitcairn Islands is among the group of PICTs (Group 1) where the estimated sustainable production of fish and invertebrates from coastal habitats will be more than enough to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Current contributions of fish to food security

Average national fish consumption in Pitcairn Islands is estimated to be 148 kg per person per year[1], well above the recommended levels for good nutrition. Because the total population is only 66 people, coastal habitats in Pitcairn Islands are estimated to be able to supply > 2000 kg of fish per person per year.

Effects of population growth

The population in Pitcairn Islands is projected to remain stable over this century and coastal fisheries are expected to continue to provide a very large surplus of fish.

Additional effects of climate change

The effects of climate change on coastal fisheries are not expected to have a noticeable effect on the fish available per person for food security in Pitcairn Islands. The large area of coral reefs relative to population size will continue to supply the fish needed in 2100, even if there is up to a 50% reduction in the productivity of demersal fish.

Livelihoods

Current contributions

Apart from the estimates that the commercial fish catch in Pitcairn Islands was ~ 5 tonnes in 2007, there is little information on opportunities to earn income from coastal fisheries in Pitcairn Islands. Some of the fish caught is sold to passing ships and yachts.

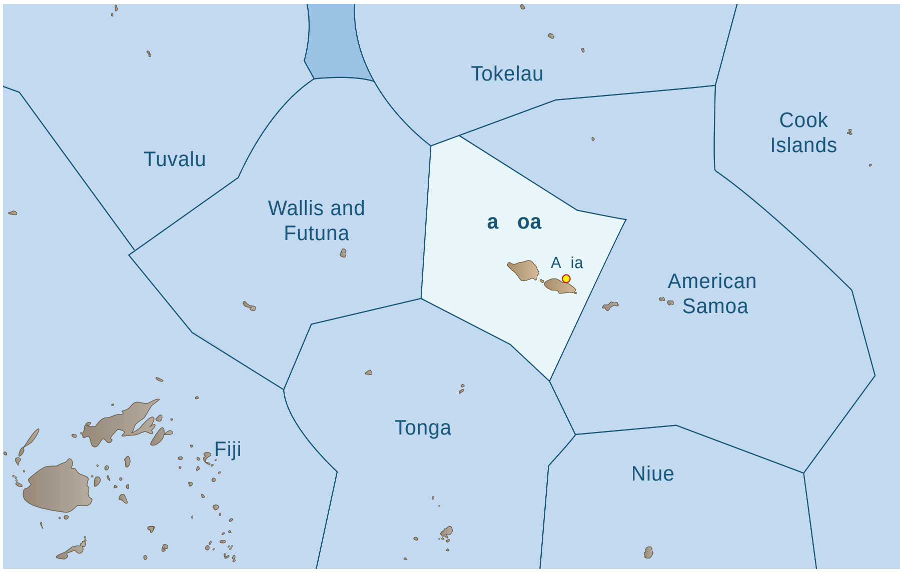
Adaptations and suggested policies

The key adaptations for maintaining the benefits from coastal fisheries for food in the face of climate change involve continued management of fish habitats and stocks.

Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F2	Foster the care of coastal fish habitats	F1–F3, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18

2.16 Samoa



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	183	202	210	240
Population growth rate[a]	0.3	0.3	0.3	0.4

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 110,365

Land area (km²) 2935

Land as % of EEZ 2.6

Fisheries and aquaculture activities: Oceanic fisheries, coastal fisheries, freshwater and estuarine fisheries and coastal and pond aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Te Vaka Moana Arrangement; South Pacific Tuna and Billfish subcommittee.

Surface climate and the ocean

Existing features

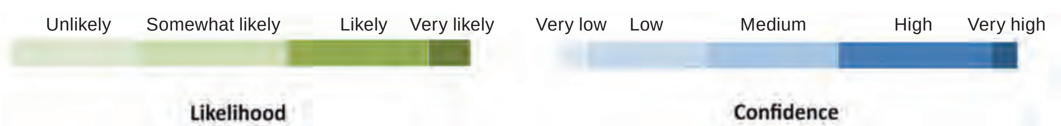
Samoa has a tropical climate {Chapter 2}. Recent air temperatures in Apia have averaged 27.0°C and average rainfall is > 2800 mm per year. Samoa lies within the South Pacific Subtropical Gyre Province (SPSG) {Chapter 4, Figure 4.6}. The SPSG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}.

Projected changes to surface climate

Air temperatures and rainfall in Samoa are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.0 (Apia)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	2840 (Apia)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones	1.3	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Samoa, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Samoa relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	28.9[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

Samoa has a local longline fishery targeting albacore tuna within and outside its exclusive economic zone (EEZ). The recent average annual catch (2004–2008) by this fishery has been 2540 tonnes, worth USD 13 million. Samoa also licenses foreign vessels to fish for tuna within its EEZ, although catches by these fleets between 1999 and 2008 averaged only 60 tonnes. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Longline	2502	13
Other oceanic fish[a]	37	0.04
Total	**2540**	**13.04**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

Samoa's EEZ lies within the generally nutrient-poor waters of the SPSG Province {Chapter 4, Figure 4.6}. This province is characterised by downwelling and low nitrate concentrations in deeper waters. Net primary production is low, particularly in summer when there is the formation of a marked thermocline {Chapter 4, Section 4.4.3}. Local upwelling around islands can result in small areas of enriched surface productivity. In general, however, the SPSG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the SPSG Province is projected to increase and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease slightly in SPSG {Chapter 4, Table 4.3}.

SPSG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+4	+7	+7	+14
Location	Poleward extension of southern limit			
Net primary production	-3	-5	-3	-6
Zooplankton biomass	-3	-4	-5	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Samoa are expected to increase significantly in 2035 and 2100, relative to the 20-year average (1980–2000). Catches of bigeye tuna are projected to remain relatively stable under both scenarios in 2035 and B1 in 2100, and to decrease slightly under A2 in 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward and to be more abundant at the edges of the SPSG Province.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+44	+49	+55	+1	+1	-4

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Samoa are made up mainly of three components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 8624 tonnes in 2007, worth > USD 34.5 million. The commercial catch was ~ 4200 tonnes. Demersal fish are estimated to make up ~ 50% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	4419	2550	0	1655	8624	34.5
Contribution (%)[a]	51	30	0	19	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch comprised equally of tuna and non-tuna species.

Existing coastal fish habitat

Samoa has > 460 km^2 of coral reef habitat {Chapter 5}, as well as relatively small areas of mangroves, seagrasses, and intertidal sand and mud flats {Chapter 6} that support important coastal fisheries species.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	466	7.5	n/a	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Samoa, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	-5 to -20	-5 to -35	-10 to -50

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish and intertidal and subtidal invertebrates in Samoa are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relative importance of demersal fish, balanced in the short term by the projected increase in productivity of the nearshore pelagic component of the fishery. As a result, total catches from coastal fisheries in Samoa are projected to increase slightly under both scenarios in 2035 but decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	51	-3.5	-2	-20	-10	-35	-18
Nearshore pelagic fish	30	+17.5	+5	+20	+6	+10	+3
Inter/subtidal invertebrates	19	0	0	-5	-1	-10	-2
Total catch[a]			**+3**		**-5**		**-17**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Samoa; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in Samoa include tilapia, eels and *Macrobrachium*. These species are mostly taken by subsistence fisheries. The estimated annual freshwater fish catch in 2007 was 10 tonnes, worth USD 33,200 {Chapter 10}[1].

Existing freshwater and estuarine fish habitat

The larger rivers of Samoa provide a limited range of freshwater and estuarine fish habitats for supporting fish and invertebrate communities {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km^2)	River length (km)
Savai'i	Sili	51	11
Upolu	Vaisigano	33	12

Projected changes to freshwater and estuarine fish habitat

The projected increase in rainfall for Samoa {Chapter 2, Section 2.5.2} is expected to result in small increases in the area and quality of all freshwater fish habitats {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	**B1 2100***	**A2 2100**
-5 to +5	-5 to +5	-5 to +10

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Higher projected rainfall and river flows are expected to result in slightly improved production from freshwater and estuarine fisheries in Samoa under the A2 emissions scenario in 2100. River flow increases the availability and quality of habitats, provides cues for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	**B1 2100***	**A2 2100**
0	0	+2.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

Aquaculture activities in Samoa centre on pond aquaculture of tilapia for food security. Production of marine ornamentals (e.g. giant clams) in coastal waters has also been investigated but commercially viable operations have yet to be established.

Existing and projected environmental features

Higher rainfall and air temperatures are expected to have positive effects on the growth and survival of tilapia. However, increasing SST, rainfall and ocean acidification, and possibly stronger storm surge from more severe cyclones, are eventually expected to reduce the number of sites where ornamental products can be successfully grown {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.0[a]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	2840[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Cyclones (no. per year)	1.3	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	28.9	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

* Approximates A2 in 2050; a = data for Apia.

Projected changes in aquaculture production

The projected effects of climate change on aquaculture are mixed. Pond aquaculture is expected to be enhanced by increased rainfall, river flows, and warmer temperatures, provided ponds are located where they will not be affected by floods or storm surge. Potential commodities for coastal aquaculture are likely to be affected adversely by climate change {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Existing				
Tilapia	Food security			
Potential				
Marine ornamentals	Livelihoods			

* Approximates A2 in 2050.

Economic and social implications

Economic development and government revenue

Current contributions

The locally-based longline fishery for tuna contributed 0.6% to the gross domestic product (GDP) of Samoa in 2007 {Chapter 12}. Licence fees from foreign vessels in the surface fishery contributed > 0.1% and fees from longline vessels contributed 0.02% to government revenue (GR).

Industrial fishery	Contribution to GDP*		Contribution to GR**	
	USD m	GDP (%)	USD m	GR (%)
Surface	0	0	0.3	0.1
Longline	3.3	0.6	0.04	0.02

* Information for 2007, when national GDP was USD 524 million (Gillett 2009)[1]; ** information for surface fishery for 2007, when total GR was USD 168 million, information for longline fishery is for 2003.

Projected effects of climate change

Projected changes to the contribution of tuna fisheries to GDP and GR due to the effects of climate change on the distribution and abundance of tuna are negligible. This is due largely to the small contribution that these fisheries make to the economy of Samoa {Chapter 12}.

Food security

Samoa is among the group of PICTs (Group 3) where the estimated sustainable production of fish and invertebrates from coastal habitats is unable to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Current contributions of fish to food security

Average national fish consumption in Samoa is estimated to be 87 kg per person per year[2], well above the recommended levels for good nutrition. At present, coral reefs in Samoa are estimated to be able to supply only 33 kg of fish per person per year. Much of the additional fish is tuna supplied by the nearshore pelagic fishery.

Fish consumption per person (kg)			Fish provided by subsistence catch (%)	
National	Rural	Urban	Rural	Urban
87	98	46	47	21

Effects of population growth

Samoa will have an increasing total demand for fish to meet the recommended 35 kg per person per year in the future due to predicted population growth. The current estimated shortfall of 2 kg per person per year in production of fish from coral reefs increases to 5 kg in 2035, 6 kg in 2050 and 10 kg in 2100.

Variable	2010	2035	2050	2100
Population (x 1000)	183	202	210	240
Fish available per person (kg/year)[a]	33	30	29	25
Gap (kg/person/year)[b]	2	5	6	10

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

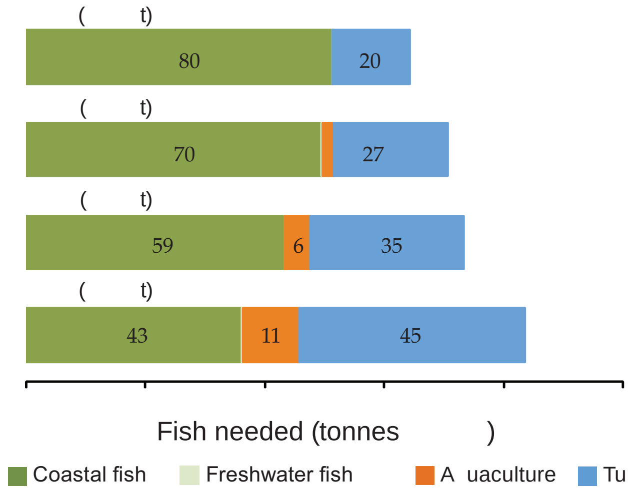
Additional effects of climate change

Samoa faces further declines in the fish available per person due to the combined effects of population growth and climate change. By 2050, climate change will cause the gap between the fish needed per person for good nutrition, and the fish available from coral reefs, to increase from 6 to 10 kg per person per year. In 2100, this gap increases from 10 to 16 kg.

Filling the gap

Tuna is the main resource available to Samoa to help supply the shortfall in fish from coastal habitats for food security. Potential also exists for pond aquaculture to provide a limited amount of fish (11% of total demand by 2100).

The implication is that an increasing proportion of the annual average tuna catch will need to be allocated over time to provide the quantities of fish recommended for good nutrition of Samoa's population. The proportions of the total amount of fish needed for food security to be contributed by tuna reach 27% in 2035, 35% in 2050, and 45% in 2100.



Fish (in tonnes) needed for future food security in Samoa, and the recommended contributions (%) of fisheries resources and aquaculture production to meet future needs.

Livelihoods

Current contributions

Large numbers of full-time and part-time jobs have been created through tuna fishing and processing in Samoa, although they represent only a low percentage of total employment in the nation. Coastal fisheries also provide important opportunities to earn income for coastal communities with ~ 50% of households in representative coastal areas deriving either their first or second source of income from catching and selling fish. Aquaculture has created relatively few jobs[4].

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
674	110	255	108	90	40	24	27	51	16

* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and pond aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario			
	Oceanic fisheries**	Coastal fisheries		Aquaculture
		Nearshore pelagic fish	Other resources	(ponds)
Present*	⇧	⇧	⇩	⇧
2035	↑	↑	↓	↑
2050	↑	↑	↓	↑
2100	↑	↑	↓	↑

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due to their subsistence role.

Percentage increase　　Percentage decrease

Adaptations and suggested policies

The plans Samoa has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. maximise access to tuna, and the efficiency of fishing operations, to provide fish for economic development and continued food security;
2. manage coastal fish habitats and fish stocks to optimise their contributions to food security; and
3. increase the number of livelihoods that can be based on fishing, tourism and pond aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E1	Full implementation of sustainable fishing effort schemes	E1, E2, E4–E6
E3	Immediate conservation management measures for bigeye tuna	E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

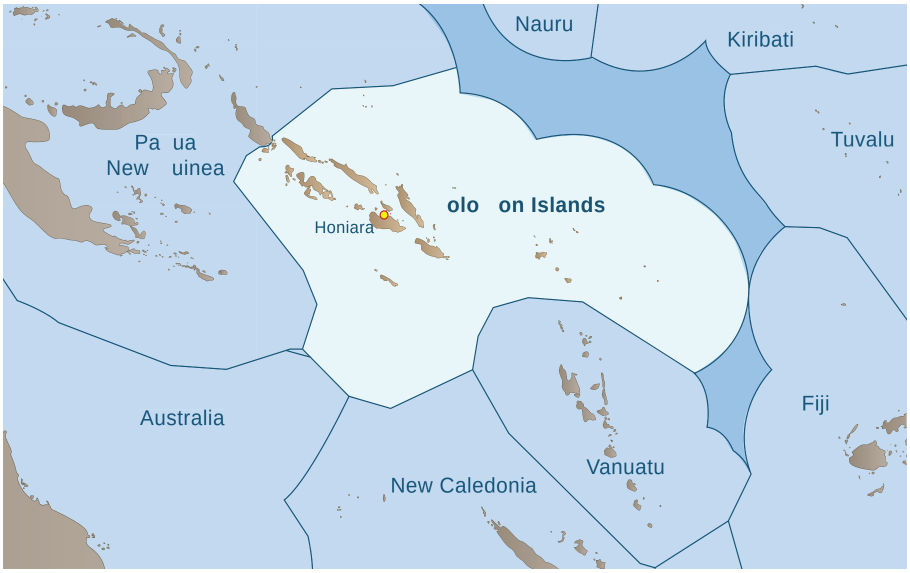
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F4	Allow for expansion of freshwater habitats	F4, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F7	Manage freshwater and estuarine fisheries to harness opportunities	
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	F13–16, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5

2.17 Solomon Islands



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	550	970	1181	1969
Population growth rate[a]	2.7	1.8	1.4	0.6

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 1,553,444

Land area (km²) 27,556

Land as % of EEZ 1.74

Fisheries and aquaculture activities: Oceanic fisheries, coastal fisheries, freshwater and estuarine fisheries, and coastal aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Parties to the Nauru Agreement; South Pacific Tuna and Billfish Subcommittee; Melanesian Spearhead Group.

Surface climate and the ocean

Existing features

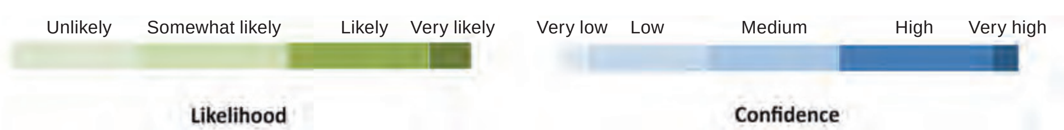
Solomon Islands has a tropical climate {Chapter 2}. Recent air temperatures in Honiara have averaged 27.4°C and average rainfall is ~ 1880 mm per year. Solomon Islands lies mainly within the Western Pacific Warm Pool Province (Warm Pool) {Chapter 4, Section 4.3}. The primary influence on surface climate is the El Niño-Southern Oscillation (ENSO), which also affects the surrounding ocean. Under normal conditions the net primary production (NPP) in the ocean is low due to the deep thermocline. However, NPP increases during El-Niño episodes because the thermocline becomes shallower.

Projected changes to surface climate

Air temperatures and rainfall in Solomon Islands are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.4 (Honiara)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1878 (Honiara)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	1.1	➢ Total number of tropical cyclones may decrease			
		➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Solomon Islands, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Solomon Islands relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents, such as the South Equatorial Current and the South Equatorial Counter Current, and the area of the Warm Pool, are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	28.8[b]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	SEC decreases at equator; EUC becomes shallower; SECC decreases and retracts westward			
Warm Pool area (x 10^6 km^2)[a]	7	+230% (20–26)	+250% (22–27)	+480% (36–46)	+770% (48–65)
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = Warm Pool defined as area with temperature above 29°C; b = average for EEZ derived from the HadISST dataset; SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current.

Oceanic fisheries

Recent catch and value

Solomon Islands has a significant national tuna fishery within its exclusive economic zone (EEZ) based on purse-seining and pole-and-line fishing. Recent average catches by this fishery (2004–2008) have exceeded 22,600 tonnes per year, worth ~ USD 30 million. Solomon Islands also licenses foreign fleets to fish for tuna in its EEZ. The average annual catch by foreign purse-seine and pole-and-line fleets between 1999 and 2008 was ~ 49,500 tonnes, worth > USD 46.5 million {Chapter 12}. Foreign longline fleets also landed an average of > 4000 tonnes of fish per year between 1999 and 2008, worth > USD 12 million. Significant catches from foreign purse-seine vessels (which average > 65,000 tonnes per year) are landed in Solomon Islands for transhipping. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Purse-seine	17,870	21.2
Pole-and-line	4540	7.3
Longline	190	1
Other oceanic fish[a]	16	0.02
Total	**22,616**	**29.52**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The Warm Pool is generally poor in nutrients, although net primary production increases during El Niño events, when the depth of the thermocline decreases, bringing more nutrient-rich waters within the photic zone {Chapter 4, Section 4.3.2}. The convergence of the Warm Pool and the Pacific Equatorial Divergence (PEQD) Province {Chapters 4 and 8} creates prime feeding areas for tuna. Changes in the position of this convergence zone due to the El Niño-Southern Oscillation influence the abundance of tuna in the EEZ of Solomon Islands {Chapter 8}.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the Warm Pool is projected to expand {Chapter 4, Table 4.3}. The greater stratification of the water column in the Warm Pool due to higher sea surface temperature {Chapter 3}, and the increased depth of the nutricline {Chapter 4}, are projected to reduce net primary production within the EEZ of Solomon Islands. Relocation of the convergence zone between the Warm Pool and PEQD to the east is also expected to increase the distance between Solomon Islands' EEZ and the prime feeding grounds for tuna {Chapter 8}.

Warm Pool feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+18	+21	+26	+48
Location	Eastwards			
Net primary production	-7	-5	-9	-9
Zooplankton biomass	-6	-3	-9	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ and archipelagic waters of Solomon Islands are expected to increase slightly in 2035, relative to the 20-year average (1980–2000). However, catches of skipjack and bigeye tuna are projected to decrease under A2 in 2050, and under both scenarios in 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+3	-5	-15	0	-3	-7

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Solomon Islands are made up of four components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, Spanish mackerel, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be > 18,000 tonnes in 2007, worth > USD 14 million. The commercial catch was 3250 tonnes. Demersal fish are estimated to make up ~ 50% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	8925	5750	950	2625	18,250	14.3
Contribution (%)[a]	49	31	5	15	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

Solomon Islands has > 8500 km^2 areas of coral reef, and significant areas of mangroves, deepwater and intertidal seagrasses, and intertidal sand and mud flats, that support many important coastal fisheries species.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km²)	8535	525	66	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Solomon Islands, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	-5 to -20	-5 to -30	-10 to -35

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

All categories of coastal fisheries in Solomon Islands are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna comprise part of the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relatively high reliance on demersal fish and the projected decrease in productivity of all components of the fishery. As a result, total catches from coastal fisheries in Solomon Islands are projected to decrease slightly under both scenarios in 2035, and continue to decline under A2 in 2050, and under both scenarios in 2100, particularly under A2.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	49	-3.5	-2	-20	-10	-35	-17
Nearshore pelagic fish	31	0	0	-10	-3	-17.5	-6
Targeted invertebrates	5	-3.5	-0.2	-10	-0.5	-20	-1
Inter/subtidal invertebrates	15	0	0	-5	-0.7	-10	-1
Total catch[a]			**-2**		**-14**		**-25**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Solomon Islands; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in Solomon Islands include flagtails (jungle perch), freshwater snappers, mullet, eels, gobies, whitebait and *Macrobrachium*. These species are taken mostly by subsistence fishers but some species have potential value for recreational fisheries. The estimated annual freshwater fish catch in 2007 was 2000 tonnes, worth USD 1.5 million {Chapter 10}.

Existing freshwater and estuarine fish habitat

The larger rivers of Solomon Islands provide a diversity of freshwater and estuarine fish habitats. Lake Tegano on the island of Rennell is the largest lake in the non-continental islands of the Pacific. The low lakes of Tetepare Island (Lakes Bangatu and Saromana) also have diverse fish communities {Chapter 7, Section 7.2.5.6}.

Island	Largest river	Catchment area (km^2)	River length (km)
Malaita	Wairaha	486	33
Guadalcanal	Lungga	394	50
Rennell	Lake Tegano	155[a]	-

a = Actual surface area of lake.

Projected changes to freshwater and estuarine fish habitat

The higher projected rainfall for Solomon Islands {Chapter 2, Section 2.5.2} is likely to result in increases in the area and quality of all freshwater fish habitats {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	**B1 2100***	**A2 2100**
-5 to +10	-5 to +20	+5 to +10

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Higher projected rainfall and river flows are expected to result in slightly improved production from freshwater and estuarine fisheries in Solomon Islands. River flow increases the availability and quality of habitats, provides cues for fish migration, and enhances reproduction and recruitment {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	**B1 2100***	**A2 2100**
0 to +2.5	+7.5	+7.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

Aquaculture commodities in Solomon Islands are mainly those produced for livelihoods in coastal waters such as seaweed (400 tonnes in 2009) and marine ornamentals (e.g. giant clams and coral fragments). Penaeid shrimps and *Macrobrachium* have been produced in the past, and there may be opportunities to grow these species again in the future. There are good prospects for freshwater pond aquaculture for food security, based on Nile tilapia and milkfish. Research has also been done to pave the way for development of pearl farming, and releasing cultured sea cucumbers, giant clams and trochus into the wild.

Existing and projected environmental features

Increasing SST and rainfall is expected to reduce the number of sites where seaweed can be successfully grown {Chapter 11}. Survival and growth of ornamental products, pearl oyster spat, sea cucumbers and trochus are also likely to be affected adversely by higher SST and rainfall, and increasing acidification of the ocean {Chapter 11}. Higher rainfall and air temperatures are expected to favour conditions for pond aquaculture in Solomon Islands.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.3[a]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	1878[a]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
Cyclones (no. per year)	1.1	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	28.8	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

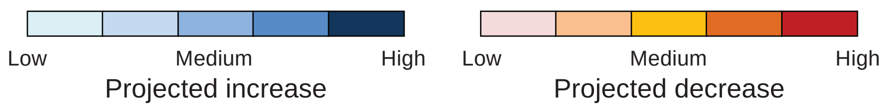
* Approximates A2 in 2050; a = data for Honiara.

Projected changes in aquaculture production

The projected effects of climate change on aquaculture in Solomon Islands are mixed. The production of commodities in coastal waters is likely to be affected adversely by increases in SST, rainfall, ocean acidification and possibly stronger storm surge from more severe cyclones {Chapter 11, Table 11.5}. Any development of pond aquaculture in Solomon Islands is expected to be enhanced by increased rainfall, river flows and warmer temperatures, provided ponds are located where they will not be affected by floods or storm surge.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Existing				
Seaweed	Livelihoods			
Marine ornamentals	Livelihoods			
Potential				
Tilapia	Food security			
Milkfish	Food security			
Pearls	Livelihoods			
Freshwater prawn	Livelihoods			
Sea cucumber	Livelihoods			
Trochus	Livelihoods			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The locally-based surface tuna fishery contributed 3.1% and the longline fishery 0.2%, to the gross domestic product (GDP) of Solomon Islands in 2007 {Chapter 12}. When the value of processing tuna is added to fishing operations, the average combined contribution to GDP increased to 4.6%, worth USD 22 million. Licence fees from foreign purse-seine vessels (and national vessels) contributed > 4% to government revenue (GR) in 2007.

Industrial fishery	Contribution to GDP*		Contribution to GR	
	USD m	GDP (%)	USD m	GR (%)
Surface[a]	14	3.1	11.8	4.4
Longline	1.1	0.2	0	0

* Information for 2007, when national GDP was USD 457 million and GR was USD 267 million (Gillett 2009)[1]; a = locally-based purse-seine and pole-and-line fleets.

Projected effects of climate change

The projected range of changes to GDP and government revenue due to the effects of climate change on the distribution and abundance of tuna are expected to be relatively minor under the A2 emissions scenario due to the size of the economy of Solomon Islands {Chapter 12}.

Projected changes to GDP (%)**			Projected changes to GR (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+0.1 to +0.2	-0.1 to -0.3	-0.3 to -0.8	0 to +0.2	0 to -0.3	0 to -0.8

* Approximates A2 in 2050; ** information for 2007, when GDP was USD 457 million and GR was USD 267 million (Gillet 2009)[1].

Food security

Solomon Islands is among the group of PICTs (Group 3) where the estimated sustainable production of fish and invertebrates from coral reefs and other coastal habitats will not supply the future population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Solomon Islands is estimated to be 33 kg per person per year[2], close to the recommended levels for good nutrition. At present, coastal habitats in Solomon Islands are estimated to be able to supply a surplus of 15 kg of fish per person per year above the recommended 35 kg.

Fish consumption per person (kg)			Animal protein from fish (%)		Fish provided by subsistence catch (%)	
National	Rural	Urban	Rural	Urban	Rural	Urban
33	31	45	94	83	73	13

Effects of population growth

Solomon Islands will have a rapidly increasing total demand for fish for food security due to the large predicted growth in its population. Therefore, the current estimated fish surplus changes to a shortfall of 7 kg per person per year in 2035, 12 kg in 2050 and 21 kg in 2100.

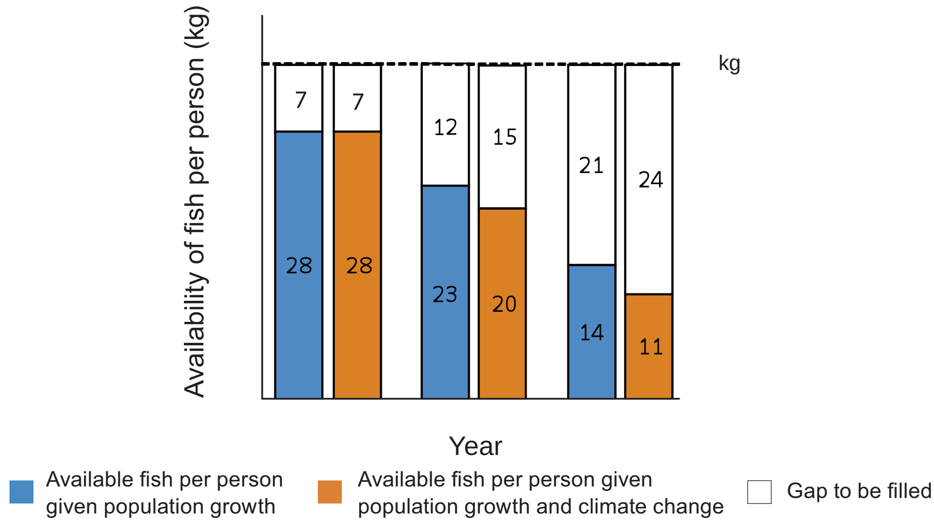
Variable	2010	2035	2050	2100
Population (x 1000)	550	970	1181	1969
Fish available per person (kg/year)[a]	50	28	23	14
Gap (kg/person/year)[b]	(+15)	7	12	21

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Additional effects of climate change

Solomon Islands faces further declines in the fish available per person due to the combined effects of population growth and climate change. By 2050, climate change will cause the gap between the fish needed per person for good nutrition, and the fish available from coral reefs, to increase from 12 to 15 kg per person per year. By 2100, the gap is estimated to increase from 21 to 24 kg per person per year.

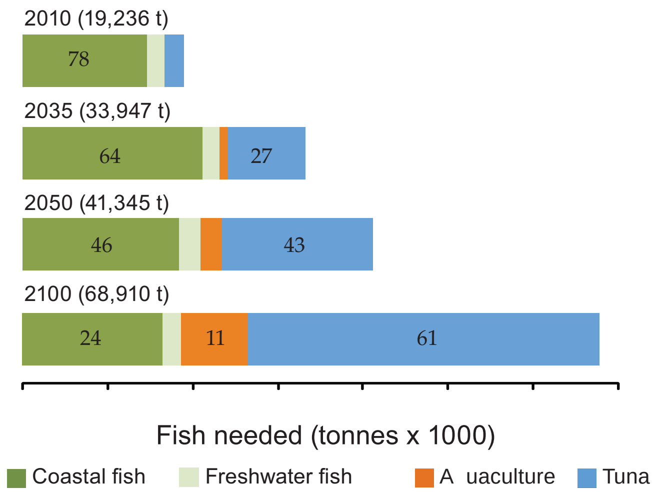


Relative effects of population growth and climate change (A2 emissions scenario) on recommended annual fish consumption in Solomon Islands.

Filling the gap

Tuna is the only resource available to Solomon Islands that can supply the shortfall in fish from coral reefs and other coastal habitats for food. This gap will need to be filled by tuna because freshwater fisheries and any development of pond aquaculture are only expected to be able to provide minor quantities of fish. The role of tuna becomes increasingly important in 2050 and 2100. Pond aquaculture could be important where access to more tuna is difficult to provide.

The implication is that an increasing proportion of the annual average tuna catch will need to be allocated over time to provide the quantities of fish recommended for good nutrition of the nation's population. The proportions of the total amount of fish needed for food security to be contributed by tuna reach 27% in 2035, 43% in 2050, and 61% in 2100.



Fish (in tonnes) needed for future food security in Solomon Islands, and the recommended contributions (%) of fisheries resources and aquaculture production required to meet future needs.

Livelihoods

Current contributions

Large numbers of full-time and part-time jobs have been created through tuna fishing and processing in Solomon Islands, although they represent only a low percentage of total employment in the nation due to the relatively large population. Coastal fisheries also provide important opportunities to earn income for coastal communities, with > 60% of households in representative coastal communities deriving their first or second incomes from catching and selling fish. Aquaculture provides > 600 jobs, mainly through seaweed farming[4].

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
464	66	107	422	330	827	29	32	61	610

* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and pond aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario				
	Oceanic fisheries**	Coastal fisheries		Aquaculture	
		Nearshore pelagic fish	Other resources	Ponds	Coastal
Present*	⇧	⇧	⇩	⇧	⇧
2035	↑	No effect	↓	↑	↓
2050	No effect	↓	↓	↑	↓
2100	↓	↓	↓	↑	↓

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due to their subsistence role.

Percentage increase

Percentage decrease

Adaptations and suggested policies

The plans Solomon Islands has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. secure access to the tuna required for canneries, and maximise the efficiency of industrial fishing operations;
2. increase access to tuna to provide the fish needed for food security for both rural and urban communities; and
3. increase the number of livelihoods that can be based on tuna fishing and processing, and on aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E1	Full implementation of sustainable fishing effort schemes	E1, E2, E4–E6
E2	Diversify sources of fish for canneries	E1–E5, E7
E3	Immediate conservation management measures for bigeye tuna	E7, E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E6	Gender-sensitive fish processing operations	
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

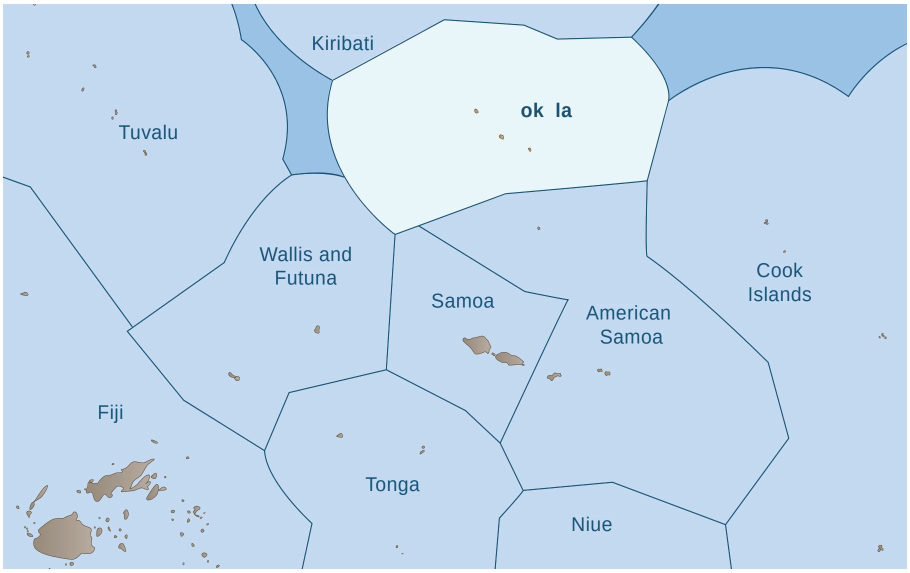
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F4	Allow for expansion of freshwater habitats	F4, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F7	Manage freshwater and estuarine fisheries to harness opportunities	
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	F13–16, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.18 Tokelau



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	1.2	1.2	1.2	1.2
Population growth rate[a]	-0.2	-0.1	0	0

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 318,990

Land area (km²) 10

Land as % of EEZ 0.003

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission (participating territory); Te Vaka Moana Arrangement; South Pacific Tuna and Billfish Subcommittee.

Surface climate and the ocean

Existing features

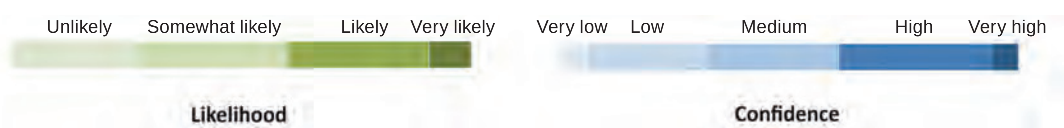
Tokelau has a tropical climate {Chapter 2}. Recent air temperatures in Pukapuka have averaged 24.4°C and average rainfall is 2925 mm per year. Tokelau lies within the Pacific Equatorial Divergence Province (PEQD) {Chapter 4, Figure 4.6}. The PEQD Province is generated by the effects of the earth's rotation on the South Equatorial Current, which results in significant upwelling of nutrients {Figure 4.3}. These conditions create the richest surface waters in the region.

Projected changes to surface climate

Air temperatures and rainfall in Tokelau are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	24.4[b]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	2925[c]	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	0.6	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Tokelau, see www.cawcr.gov.au/projects/PCCSP; b = 1985–1999 data from Pukapuka in Cook Islands used as a surrogate for Tokelau; c = 1975–1999 data from Pukapuka in Cook Islands.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Tokelau relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents, such as the South Equatorial Current, and the area and location of the PEQD Province, are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	29.3[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	SEC decreases at equator; EUC becomes shallower; SECC decreases and retracts westward			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset; SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current.

Oceanic fisheries

Recent catch and value

Tokelau has only a very small local fishery for tuna within its exclusive economic zone (EEZ), with recent average catches (2004–2008) of ~ 6 tonnes per year, worth > USD 14,000. Tokelau also licenses foreign purse-seine fleets to fish in its EEZ. The average annual catch by these fleets between 1999 and 2008 was 2665 tonnes, worth USD 2 million. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD)* 2004–2008
Tuna		
Troll	6.2	14,385
Total	**6.2**	**14,385**

* Calculated using market value per tonne for 2004–2008.

Existing oceanic fish habitat

The waters of the PEQD Province are characterised by high-salinity, nutrient-rich waters, and an abundance of phytoplankton {Chapter 4, Figure 4.7}. However, primary production in PEQD is limited by low iron concentrations {Chapter 4, Figure 4.9}. The prime feeding areas for tuna are located to the northwest of Tokelau at the convergence of PEQD and the Warm Pool {Chapters 4 and 8}.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the PEQD Province is projected to contract and the convergence zone with the Warm Pool is expected to move eastward. However, there are likely to be only minor changes in the key components of the food web for tuna (e.g. net primary production and zooplankton biomass) in PEQD {Chapter 4, Table 4.3}.

PEQD feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	-20	-27	-30	-50
Location	Eastwards			
Net primary production	0	0	+2	+4
Zooplankton biomass	-2	-2	-3	-6

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Tokelau are expected to increase by > 60% in 2035 and 2100, relative to the 20-year average (1980–2000). However, catches of bigeye tuna are projected to decrease progressively under both scenarios in 2035 and 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+61	+69	+63	-3	-6	-16

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Tokelau are made up mainly of three components: demersal fish (bottom-dwelling fish associated with coral reef habitat), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 375 tonnes in 2007, worth > USD 710,000. There was no commercial catch. Demersal fish are estimated to make up ~ 50% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	182	150	0	43	375	0.7
Contribution (%)[a]	48	40	0	12	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by tuna species.

Existing coastal fish habitat

Tokelau has 204 km² of coral reef habitat that supports many coastal fisheries species {Chapter 5}. There are no mangroves or seagrasses in Tokelau and the area of intertidal sand flats within lagoons has not been documented {Chapter 6}.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs in Tokelau, resulting in significant declines in coral cover in the medium and long term {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish and intertidal and subtidal invertebrates in Tokelau are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change

{Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the relative importance of demersal fish and the projected increase in productivity of nearshore pelagic fish. As a result, potential catches from coastal fisheries in Tokelau are expected to increase under both scenarios in 2035, decrease under B1 in 2100 (A2 in 2050), and decrease further under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	48	-3.5	-2	-20	-10	-35	-17
Nearshore pelagic fish	40	+17.5	+7	+20	+8	+10	+4
Inter/subtidal invertebrates	12	0	0	-5	-0.5	-10	-1
Total catch[a]			**+5**		**-2**		**-14**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Tokelau; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Tokelau has no freshwater or estuarine fisheries.

Aquaculture

Tokelau has no aquaculture production.

Economic and social implications

Economic development and government revenue

Current contributions

Licence fees from foreign surface fishery vessels contributed 11.4% to government revenue (GR) in 2007. Estimates of the gross domestic product (GDP) of Tokelau were not available {Chapter 12}.

Industrial fishery	Contribution to GR*	
	USD m	GR (%)
Surface	1.5	11.4

* Information for 2007, when total government revenue was USD 13 million.

Projected effects of climate change

The effects of climate change on the distribution and abundance of tuna are projected to increase the contribution of tuna licence fees to government revenue in the medium and long term. Potentially, contributions to GR could increase from ~ 11% to up to ~ 20% (assuming total GR remained constant) {Chapter 12}.

Projected changes to GR (%)		
B1/A2 2035	B1 2100*	A2 2100
+1 to +9	+1 to +10	+1 to +9

* Approximates A2 in 2050.

Food security

Tokelau is among the group of PICTs (Group 1) where the estimated sustainable production of fish and invertebrates from coastal habitats will be more than enough to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Tokelau is estimated to be ~ 200 kg per person per year[1], well above the recommended levels for good nutrition. At present, coral reefs in Tokelau are estimated to be able to supply > 500 kg of fish per person per year.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Effects of population growth

The population in Tokelau is projected to remain stable over this century and coastal fisheries are expected to continue to easily meet the demand for fish for food security. The current estimated fish surplus of > 400 kg is expected to continue in 2035, 2050 and 2100.

Variable	2010	2035	2050	2100
Population	1200	1200	1150	1150
Fish available per person (kg/year)[a]	510	510	532	532
Surplus (kg/person/year)[b]	475	475	497	497

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The projected decline in coastal fisheries in Tokelau due to climate change is not expected to have any significant effect on the fish available per person for food security. The large area of coral reef relative to population size will continue to supply enough fish to meet the traditional demand.

Livelihoods

Current contributions

There are no estimates of the number of jobs supported by the small local tuna fishery in Tokelau. There are no commercial coastal fishing activities and no information was available on possible opportunities to gain income from coastal fisheries.

Adaptations and suggested policies

The plans Tokelau has to derive greater socio-economic benefits from fisheries will depend heavily on interventions to:

1. improve access of foreign fleets to tuna with in its EEZ, and manage coastal fish habitats and fish stocks to ensure that these resources continue to provide a surplus of fish for food security.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E1	Full implementation of sustainable fishing effort schemes	E1, E2, E4–E6
E3	Immediate conservation management measures for bigeye tuna	E8
E7	Safety at sea	E10
E9	Pan-Pacific tuna management	E2

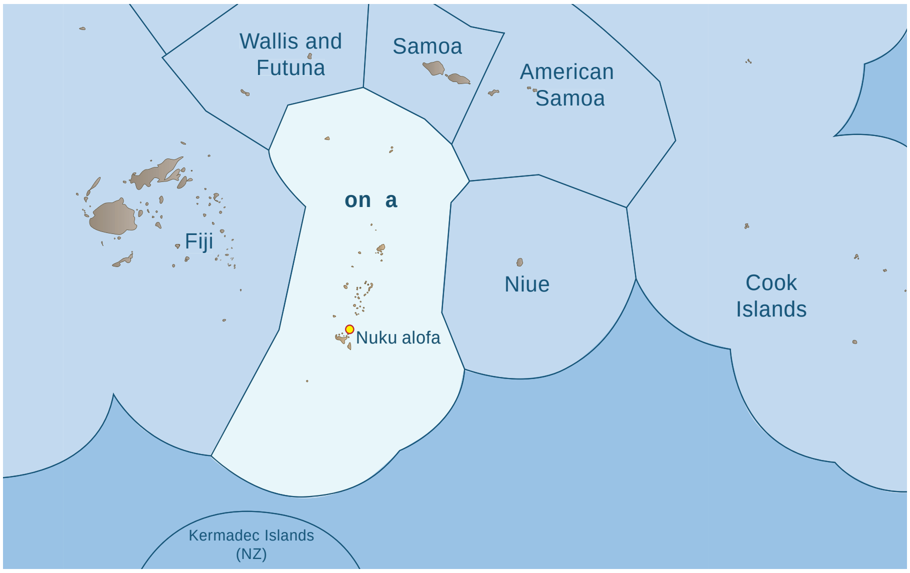
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F2	Foster the care of coastal fish habitats	F1–F3, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2

2.19 Tonga



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	103	115	123	147
Population growth rate[a]	0.3	0.4	0.4	0.8

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km^2) 676,401

Land area (km^2) 699

Land as % of EEZ 0.1

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries, with some freshwater and estuarine fisheries, and some coastal aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Te Vaka Moana Arrangement; South Pacific Tuna and Billfish Subcommittee.

Surface climate and the ocean

Existing features

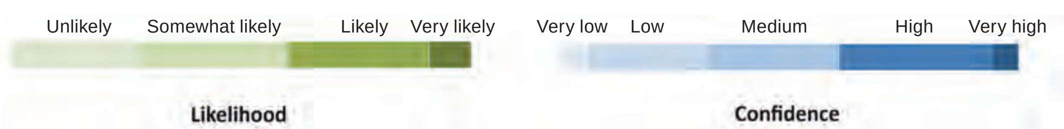
Tonga has a tropical to subtropical climate {Chapter 2}. Recent air temperatures in Nuku'alofa have averaged 24.1°C and average rainfall is 1522 mm per year. Tonga lies within the South Pacific Subtropical Gyre Province (SPSG) {Chapter 4, Figure 4.6}. The SPSG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}.

Projected changes to surface climate

Air temperatures in Tonga are projected to increase, and rainfall is expected to decrease in the dry season and increase in the wet season, due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	24.1 (Nuku'alofa)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	1522 (Nuku'alofa)	-5 to -10%	-5 to -20%	-5 to -20%	-5 to -20%
		More extreme wet and dry periods			
Cyclones (no. per year)	1.7	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Tonga, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Tonga relative to the long-term averages are expected to result in increases to sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	25.9[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

Tonga has a small longline fishery in its exclusive economic zone (EEZ) with an average annual catch (2004–2008) of > 700 tonnes, worth ~ USD 3.4 million. Foreign longline fleets caught an average of 137 tonnes of tuna per year in Tonga's EEZ between 1999 and 2008 {Chapter 12}. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Longline	646	3.3
Other oceanic fish[a]	60	0.06
Total	**706**	**3.36**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

Tonga's EEZ lies within the generally nutrient-poor waters of the SPSG Province {Chapter 4, Figure 4.6}. This province is characterised by downwelling and low nitrate concentrations in deeper waters. Net primary production is low, particularly in summer when there is the formation of a marked thermocline {Chapter 4, Section 4.4.3}. Local upwelling around islands can result in small areas of enriched surface productivity. In general, however, the SPSG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the SPSG Province is projected to increase and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease in SPSG {Chapter 4, Table 4.3}.

SPSG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+4	+7	+7	+14
Location	Poleward extension of southern limit			
Net primary production	-3	-5	-3	-6
Zooplankton biomass	-3	-4	-5	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Tonga are expected to increase significantly in 2035 and 2100, relative to the 20-year average (1980–2000). However, catches of bigeye tuna are projected to decrease under both scenarios in 2035 and 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward and to be more abundant at the edges of the SPSG Province.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+47	+50	+58	-4	-5	-10

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Tonga are made up mainly of three components in recent years: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 6500 tonnes in 2007, worth USD 17.5 million. The commercial catch was 3700 tonnes. Demersal fish are estimated to make up > 80% of the total catch. There was no catch of targeted invertebrates in 2007 due to the moratorium of sea cucumbers. The sea cucumber fishery has now been re-opened.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	5245[c]	650	0	605	6500	17.5
Contribution (%)[a]	81	10	0	9	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch comprised equally of tuna and non-tuna species; c = includes 700 tonnes of deepwater snappers.

Existing coastal fish habitat

Tonga has > 5800 km² of coral reefs {Chapter 5} that support many important fisheries species, as well as small areas of mangrove and seagrass habitat {Chapter 6}. The area of intertidal sand and mud flat habitats has not been measured.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km²)	5811	13	n/a	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Tonga, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-30	-70	-80
Seagrass area	-5 to -10	-5 to -20	-10 to -20

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish and intertidal and subtidal invertebrates in Tonga are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna comprise part of the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the very high reliance on demersal fish and the expected decrease in productivity of this component of the fishery. As a result, total catches from coastal fisheries in Tonga are projected to decrease slightly under both scenarios in 2035, and continue to decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	81	-3.5	-3	-20	-16	-35	-28
Nearshore pelagic fish	10	+17.5	+2	+20	+2	+10	+1
Inter/subtidal invertebrates	9	0	0	-5	-0.5	-10	-1
Total catch[a]			**-1**		**-15**		**-28**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Tonga; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in Tonga include tilapia, mullet and *Macrobrachium*. These species are mostly taken by subsistence fisheries. The estimated annual freshwater fish catch in Tonga in 2007 was 1 tonne, worth ~ USD 2000 {Chapter 10}.

Existing freshwater and estuarine fish habitat

The small rivers of Tonga provide a limited range of freshwater and estuarine habitats for fish communities {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km^2)	River length (km)
'Eua	Fern Gully	2.3	2

Projected changes to freshwater and estuarine fish habitat

The projected changes in rainfall patterns in Tonga {Chapter 2, Section 2.5.2} are expected to result in greater variability in the area and quality of all freshwater fish habitats {Chapter 7, Table 7.5}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	B1 2100*	A2 2100
-5 to +5	-5 to +10	-5 to > +20

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Greater variability in rainfall under climate change is expected to result in minimal changes to total production of freshwater and estuarine fisheries in Tonga in 2035 and 2100.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
0	+2.5	+7.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

The coastal aquaculture commodities produced in Tonga include winged pearl oysters, marine ornamentals (e.g. giant clams) and trochus.

Existing and projected environmental features

Increasing SST and ocean acidification, and the possibility of increased storm surge from more powerful cyclones, could reduce the number of sites where pearl oysters, marine ornamental products and trochus can be grown successfully {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Cyclones (no. per year)	1.7	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	25.9	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

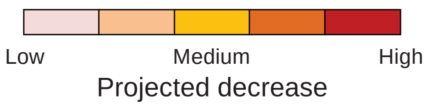
* Approximates A2 in 2050.

Projected changes in aquaculture production

The commodities grown in coastal waters are eventually likely to be affected adversely by climate change {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Pearls (mabe)	Livelihoods			
Marine ornamentals	Livelihoods			
Trochus	Livelihoods			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

The local longline fishery contributed 0.3% to the gross domestic product (GDP) of Tonga in 2007 {Chapter 12}. Licence fees from foreign vessels in the surface fishery for tuna contributed 0.2% to government revenue (GR) in 2007 {Chapter 12, Table 12.2}.

Industrial fishery	Contribution to GDP*		Contribution to GR*	
	USD m	GDP (%)	USD m	GR (%)
Surface	0	0	0.1	0.2
Longline	0.7	0.3	0	0

* Information for 2007, when national GDP was USD 238 million and GR was USD 76 million (Gillett 2009)[1].

Projected effects of climate change

Any changes to GDP and government revenue due to the effects of climate change on the distribution and abundance of tuna are expected to be relatively minor due to the small contribution of tuna fishing to the economy of Tonga {Chapter 12}.

Food security

Tonga is among the group of PICTs (Group 2) where the estimated sustainable production of fish and invertebrates from coastal habitats has the potential to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i]. However, it may be difficult to distribute the catch due to the distances between fishing areas and population centres {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Tonga is estimated to be 20 kg per person per year[2], below the recommended levels for good nutrition. At present, coral reefs in Tonga are estimated to be able to supply 169 kg of fish per person per year.

Fish consumption per person (kg)			Fish provided by subsistence catch (%)		
National	Rural	Urban	National	Rural	Urban
20	n/a	n/a	37	n/a	n/a

n/a = Data not available.

Effects of population growth

Tonga will have an increasing total demand for fish for food security due to the predicted growth in population. Coastal habitats have the potential to produce sufficient fish to meet the demand for the remainder of the century if the catch can be distributed effectively.

Variable	2010	2035	2050	2100
Population (x 1000)	103	115	123	147
Fish available per person (kg/year)[a]	169	152	142	119
Surplus (kg/person/year)[b]	134	117	107	84

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The projected declines in production of coastal fisheries due to climate change are not expected to significantly affect the fish available per person. The large area of coral reefs relative to population size has the potential to continue to supply sufficient coastal fish for food security.

Livelihoods

Current contributions

Full-time and part-time jobs have been created through tuna fishing and processing in Tonga, although they represent only a low percentage of total employment in the nation. Coastal fisheries also provide important opportunities to earn income for

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

coastal communities, with 46% of representative coastal households earning their first or second income from catching and selling fish. Twenty jobs have been created through aquaculture[4].

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture*
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
161	75	45	85	35	35	41	5	46	20

* Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and coastal aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario			
	Oceanic fisheries**	Coastal fisheries		Aquaculture (coastal)
		Nearshore pelagic fish	Other resources	
Present*	⇧	⇧	⇩	⇧
2035	⬆	⬆	⬇	⬇
2050	⬆	⬆	⬇	⬇
2100	⬆	⬆	⬇	⬇

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due to their subsistence role.

Percentage increase

Percentage decrease

Adaptations and suggested policies

The plans Tonga has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. maximise access to tuna, and the efficiency of fishing operations, to provide fish for economic development;
2. manage coastal fish habitats and fish stocks to ensure that these resources continue to provide fish for food security; and
3. increase the number of livelihoods that can be based on fishing, tourism and coastal aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

<table>
<tr><th>Adaptation no. (Section 3.2)</th><th>Summary of adaptation</th><th>Supporting policy no. (Section 3.3)</th></tr>
<tr><td>E1</td><td>Full implementation of sustainable fishing effort schemes</td><td>E1, E2, E4–E6</td></tr>
<tr><td>E3</td><td>Immediate conservation management measures for bigeye tuna</td><td>E8</td></tr>
<tr><td>E4</td><td>Energy efficiency programmes for industrial tuna fleets</td><td rowspan="2">E9</td></tr>
<tr><td>E5</td><td>Environmentally-friendly fishing operations</td></tr>
<tr><td>E7</td><td>Safety at sea</td><td>E10</td></tr>
<tr><td>E8</td><td>Climate-proof infrastructure</td><td>E11</td></tr>
<tr><td>E9</td><td>Pan-Pacific tuna management</td><td>E2</td></tr>
</table>

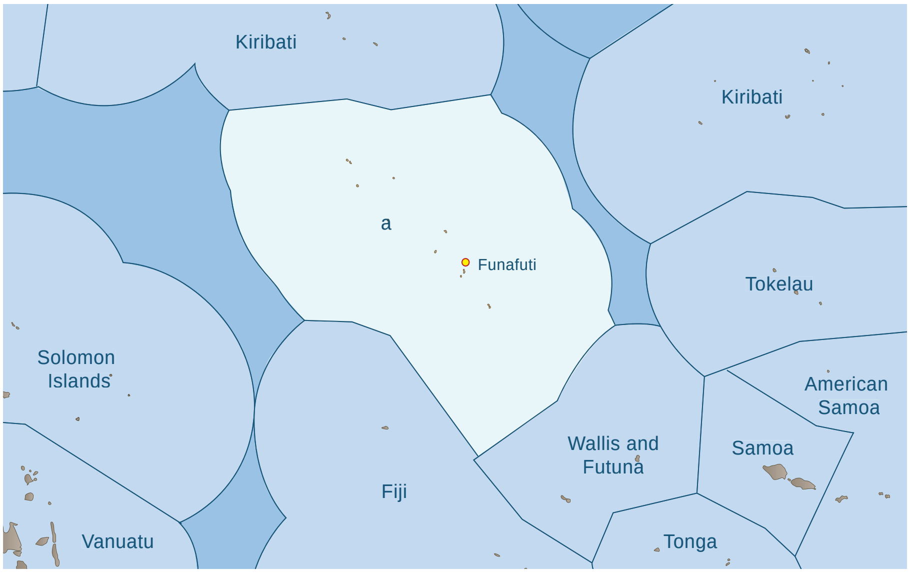
Food security

<table>
<tr><th>Adaptation no. (Section 3.4)</th><th>Summary of adaptation</th><th>Supporting policy no. (Section 3.5)</th></tr>
<tr><td>F1</td><td>Manage and restore vegetation in catchments</td><td>F1, F2, F18</td></tr>
<tr><td>F2</td><td>Foster the care of coastal fish habitats</td><td>F1–F3, F18</td></tr>
<tr><td>F3</td><td>Provide for landward migration of coastal fish habitats</td><td>F4, F5, F18</td></tr>
<tr><td>F4</td><td>Allow for expansion of freshwater habitats</td><td>F4, F18</td></tr>
<tr><td>F5</td><td>Sustain production of coastal demersal fish and invertebrates</td><td>F6, F7, F13, F18</td></tr>
<tr><td>F6</td><td>Diversify catches of coastal demersal fish</td><td rowspan="2">F6, F13, F18</td></tr>
<tr><td>F7</td><td>Manage freshwater and estuarine fisheries to harness opportunities</td></tr>
<tr><td>F8</td><td>Increase access to tuna for urban and rural populations</td><td>F8–F13, F18</td></tr>
<tr><td>F9</td><td>Develop pond aquaculture to diversify the supply of fish</td><td>F13–16, F18</td></tr>
<tr><td>F10</td><td>Develop coastal fisheries for small pelagic fish</td><td>F13, F17, F18</td></tr>
<tr><td>F11</td><td>Improve post-harvest methods</td><td>F17, F18</td></tr>
</table>

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.20 Tuvalu



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	11	13	14	19
Population growth rate[a]	0.5	0.6	0.6	0.8

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 719,174

Land area (km²) 26

Land as % of EEZ 0.004

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission; Parties to the Nauru Agreement; South Pacific Tuna and Billfish Subcommittee.

Surface climate and the ocean

Existing features

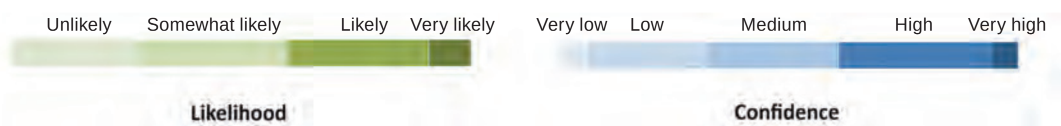
Tuvalu has a tropical climate {Chapter 2}. Recent air temperatures in Funafuti have averaged 28.2°C and average rainfall is > 3660 mm per year. Tuvalu lies within the Pacific Equatorial Divergence Province (PEQD) {Chapter 4, Figure 4.6}. The PEQD Province is generated by the effects of the earth's rotation on the South Equatorial Current, which results in significant upwelling of nutrients {Figure 4.3}. These conditions create the richest surface waters in the region.

Projected changes to surface climate

Air temperatures and rainfall in Tuvalu are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	28.2 (Funafuti)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	3666 (Funafuti)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	0.8	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Tuvalu, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Tuvalu relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents, such as the South Equatorial Current, and the area and location of the PEQD Province, are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	29.4[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	SEC decreases at equator; EUC becomes shallower; SECC decreases and retracts westward			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset; SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current.

Oceanic fisheries

Recent catch and value

Tuvalu has a very small local fishery for tuna within its exclusive economic zone (EEZ). Recent annual average catches (2004–2008) by this fishery were ~ 16 tonnes per year, worth > USD 36,000. Tuvalu also licenses foreign fleets to fish for tuna in its EEZ. These fleets made average annual catches in the surface fishery of 26,380 tonnes between 1999 and 2008, worth USD 22.6 million. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD)* 2004–2008
Tuna		
Troll	16	36,656
Total	**16**	**36,656**

* Calculated using market value per tonne for 2004–2008.

Existing oceanic fish habitat

The PEQD Province is characterised by high-salinity, nutrient-rich waters, and an abundance of phytoplankton {Chapter 4, Figure 4.7}. However, primary production in PEQD is limited by low iron concentrations {Chapter 4, Figure 4.9}. The convergence of PEQD and the Western Pacific Warm Pool creates prime feeding areas for tuna {Chapters 4 and 8}. Changes in the position of this convergence zone due to the El Niño-Southern Oscillation have a major influence on the abundance of tuna in the EEZ of Tuvalu {Chapter 8}.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the PEQD Province is projected to contract and the convergence zone with the Warm Pool is expected to move eastward. However, there are likely to be only minor changes in the key components of the food web for tuna (e.g. net primary production and zooplankton biomass) in PEQD {Chapter 4, Table 4.3}.

PEQD feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	-20	-27	-30	-50
Location	Eastwards			
Net primary production	0	0	+2	+4
Zooplankton biomass	-2	-2	-3	-6

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Tuvalu are expected to increase significantly in 2035 and 2100, relative to the 20-year average (1980–2000). Catches of bigeye tuna are projected to increase slightly under both scenarios in 2035 and under B1 in 2100, and decrease under A2 in 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+37	+41	+25	+3	+2	-6

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Tuvalu are made up mainly of three components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 1215 tonnes in 2007, worth > USD 2.8 million. The commercial catch was 226 tonnes. Demersal fish are estimated to make up ~ 70% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	837	326	0	52	1215	2.8
Contribution (%)[a]	69	27	0	4	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch comprised equally of tuna and non-tuna species.

Existing coastal fish habitat

Tuvalu has > 3000 km^2 of coral reef to support coastal fisheries species, but only a very small area of mangrove habitat. There is little or no seagrass habitat in Tuvalu. The area of intertidal sand flats within lagoons has not been measured.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	3175	0.4	0	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, and intertidal flats in Tuvalu, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area[c]	-10	-30	-60

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs; c = indicative estimates from Samoa {Chapter 6}.

Projected changes in coastal fisheries production

Fisheries for demersal fish and intertidal and subtidal invertebrates in Tuvalu are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna comprise ~ 50% of the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the strong reliance on demersal fish balanced somewhat by the projected increase in productivity of nearshore pelagic fish. As a result, total catches from coastal fisheries in Tuvalu are projected to increase slightly under both scenarios in 2035 but decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	69	-3.5	-2	-20	-14	-35	-24
Nearshore pelagic fish	27	+17.5	+5	+20	+5	+10	+3
Inter/subtidal invertebrates	4	0	0	-5	-0.2	-10	-0.4
Total catch[a]			**+2**		**-9**		**-22**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Tuvalu; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Tuvalu has no freshwater or estuarine fisheries.

Aquaculture

Trials to assess the potential for farming milkfish are underway in Tuvalu.

Existing and projected environmental features

The projected increases in air temperature and rainfall are expected to enhance the conditions for growing milkfish in Tuvalu.

Environmental feature	1980–1999 average[a]	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	28.2	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	3666	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%

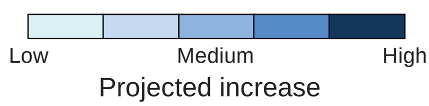
* Approximates A2 in 2050; a = data for Funafuti.

Projected changes in aquaculture production

Enterprises farming milkfish in Tuvalu are expected to be favoured by higher air temperatures and increased rainfall {Chapter 11}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Tilapia	Food security			

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

Licence fees from foreign vessels involved in the surface fishery have recently contributed 11% to government revenue (GR). The small locally-based tuna fishery does not contribute to the gross domestic product of Tuvalu {Chapter 12}.

Industrial fishery	Contribution to GR*	
	USD m	GR (%)
Surface	3.4	11

* Information for 2007, when total GR was USD 31 million.

Projected effects of climate change

The preliminary modelling of the projected effects of climate change on the distribution and abundance of skipjack tuna indicate that there could be significant increases in the contributions of licence fees from foreign fishing vessels to government revenue {Chapter 12}. For example contributions in 2035 are projected to increase by 4–9%, i.e. from ~ 11% to 15–20%.

Projected changes to GR (%)		
B1/A2 2035	B1 2100*	A2 2100
+4 to +9	+4 to +10	+2 to +6

* Approximates A2 in 2050.

Food security

Tuvalu is among the group of PICTs (Group 2) where the estimated sustainable production of fish and invertebrates from coastal habitats has the potential to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i]. However, it may be difficult to distribute the catch due to the distances between fishing areas and population centres {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Tuvalu is estimated to be 110 kg per person per year, well above the recommended levels for good nutrition[2]. In rural areas most of this fish comes from subsistence fishing and fish provides > 75% of dietary animal protein. At present, coral reefs in Tuvalu are estimated to have the potential to supply > 850 kg of fish per person per year.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Fish consumption per person (kg)			Animal protein from fish (%)		Fish provided by subsistence catch (%)	
National	Rural	Urban	Rural	Urban	Rural	Urban
110	147	69	77	41	86	56

Effects of population growth

Assuming that the catch can be distributed effectively, coral reefs in Tuvalu are presently estimated to supply a surplus of > 800 kg of fish per person per year above the basic recommended level of 35 kg. The predicated population growth in Tuvalu will increase the total demand for fish for food security. However, coastal fisheries are expected to easily meet the demand for the traditionally high levels of fish consumption for the remainder of the century, provided the potential catch can be distributed effectively.

Variable	2010	2035	2050	2100
Population (x 1000)	11	13	14	19
Fish available per person (kg/year)[a]	858	744	700	514
Surplus (kg/person/year)[b]	823	709	665	479

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The large area of coral reefs relative to future population size in Tuvalu is still expected to supply the fish needed for the traditionally high levels of consumption, even if production of demersal fish declines by up to 50% under the A2 emissions scenario by 2100 {Chapter 12}.

Livelihoods

Current contributions

Full-time and part-time jobs have been created through tuna fishing and processing in Tuvalu. Coastal fisheries also provide important opportunities to earn income for coastal communities, with almost 50% of households in representative coastal areas deriving their first or second income from catching and selling fish.

Jobs on tuna vessels			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)		
2002	2006	2008	2002	2006	2008	1st	2nd	Both
59	20	65	36	10	10	24	24	48

Information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries are difficult to estimate because there is still scope to derive new jobs from oceanic and coastal fisheries. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario		
	Oceanic fisheries**	Coastal fisheries	
		Nearshore pelagic fish	Other resources
Present*	⇧	⇧	⇩
2035	⬆	⬆	⬇
2050	⬆	⬆	⬇
2100	⬆	⬆	⬇

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches.

Percentage increase Percentage decrease

Adaptations and suggested policies

The plans Tuvalu has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. maximise access to tuna for economic development;
2. manage coastal fish habitats and fish stocks to ensure that they continue to supply fish for food security; and
3. increase the number of livelihoods that can be based on fishing and tourism.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E1	Full implementation of sustainable fishing effort schemes	E1, E2, E4–E6
E3	Immediate conservation management measures for bigeye tuna	E8
E7	Safety at sea	E10
E9	Pan-Pacific tuna management	E2

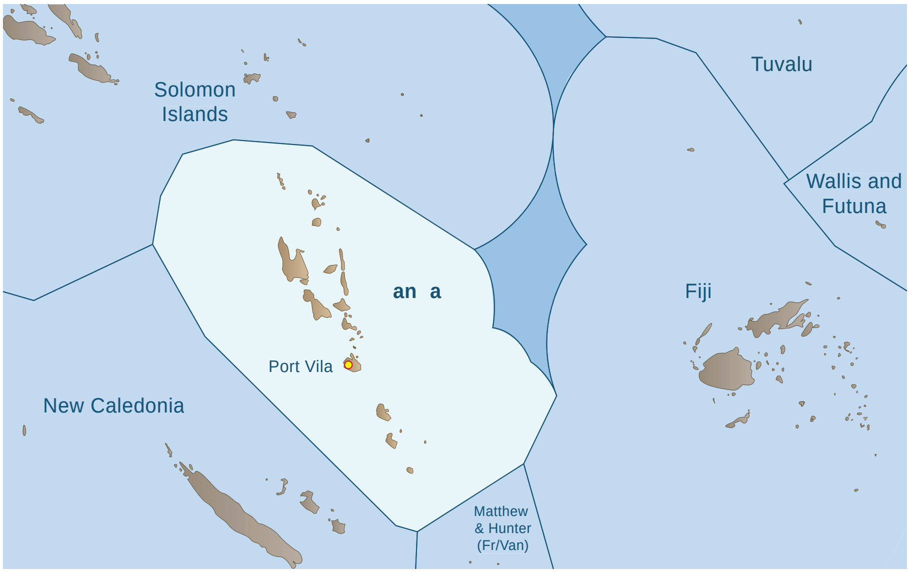
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F2	Foster the care of coastal fish habitats	F1–F3, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3

2.21 Vanuatu



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	252	400	483	695
Population growth rate[a]	2.6	1.6	1.4	0.7

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 668,220

Land area (km²) 11,880

Land as % of EEZ 1.7

Fisheries and aquaculture activities: Oceanic fisheries, coastal fisheries, freshwater and estuarine fisheries, coastal aquaculture and freshwater aquaculture.

Membership of regional fisheries management arrangements: Forum Fisheries Agency; Western and Central Pacific Fisheries Commission (including the Nothern Committee); South Pacific Regional Fisheries Management Organisation; Melanesian Spearhead Group; South Pacific Tuna and Billfish Subcommittee; Inter American Tropical Tuna Commission.

Surface climate and the ocean

Existing features

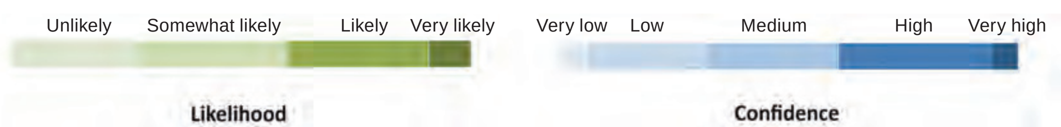
Vanuatu has a tropical climate {Chapter 2}. Recent air temperatures in Efate have averaged 24.2°C and average rainfall is > 2100 mm per year. Vanuatu lies within the Archipelagic Deep Basins Province (ARCH) {Chapter 4, Figure 4.6}. The climate and ocean within this province are influenced by a complex current regime caused by the occurrence of many islands, archipelagos and seamounts. These formations divert oceanic circulation to create eddies, resulting in upwelling, downwelling and other mesoscale processes {Chapter 3, Section 3.2.9, Figure 3.1}. ARCH Province is characterised by a patchwork of nutrient-rich and nutrient-poor water bodies that can vary over short timeframes.

Projected changes to surface climate

Air temperatures and rainfall in Vanuatu are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	24.2 (Efate)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	2118 (Efate)	-5 to -10%	-5 to -20%	-5 to -20%	-5 to -20%
		More extreme wet and dry periods			
Cyclones (no. per year)	2.6	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Vanuatu, see www.cawcr.gov.au/projects/PCCSP.



Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Vanuatu relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	27.1[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	SEC decreases at equator; EUC becomes shallower; SECC decreases and retracts westward			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset; SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current.

Oceanic fisheries

Recent catch and value

Vanuatu has a large locally-based longline fishery for tuna that operates both within and outside its exclusive economic zone (EEZ), and a purse-seine fishery that operates only outside the EEZ. Recent average catches (2004–2008) by these fisheries totalled > 72,000 tonnes per year, worth > USD 130 million. Vanuatu also licenses foreign longline fleets to fish for tuna in its EEZ. These fleets made average annual catches of > 4200 tonnes, worth ~ USD 10 million between 1999 and 2008. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Local oceanic fisheries	Average annual catch (tonnes) 2004–2008	Average annual catch value (USD million)* 2004–2008
Tuna		
Purse-seine	59,787	70.8
Longline	11,233	58.2
Other oceanic fish[a]	1265	1.3
Total	**72,285**	**130.3**

* Calculated using market value per tonne for 2004–2008; a = billfish catch only, valued at USD 1000 per tonne.

Existing oceanic fish habitat

The productivity of the waters surrounding Vanuatu is variable and typical of the ARCH Province {Chapter 4, Section 4.3.4}. Coasts and islands influence a broad range of mesoscale processes (e.g. local boundary currents, jets, wind-driven upwelling, internal waves and tidal mixing) which commonly bring nutrients to surface waters {Chapter 3, Section 3.2.9}. The food webs for tuna and other large pelagic fish in the EEZ of Vanuatu are based on nutrients derived from these mesoscale processes, and to a lesser extent on runoff from high islands.

Projected changes to oceanic fish habitat

The area of the ARCH Province remains the same by definition. However, key components of the food web (net primary production and the biomass of zooplankton) are expected to decrease significantly under the B1 and A2 scenarios by 2100 in ARCH {Chapter 4, Table 4.3}.

ARCH feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Net primary production	-5	-8	-20	-33
Zooplankton biomass	-5	-6	-17	-26

* Approximates A2 in 2050.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Vanuatu are expected to increase in 2035 and 2100, relative to the 20-year average (1980–2000). Catches of bigeye tuna are projected to decrease under both scenarios in 2035 and 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin tuna are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+18	+15	+26	-3	-6	-10

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Vanuatu are made up of four components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be 3368 tonnes in 2007, worth > USD 7.9 million. The commercial catch was 538 tonnes. Demersal fish are estimated to make up ~ 50% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	1730	753	70	815	3368	7.9
Contribution (%)[a]	51	23	2	24	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

Vanuatu has > 1200 km^2 of coral reef {Chapter 5} that support many important coastal fisheries species. Mangroves cover 25 km^2 {Chapter 6}. The areas of seagrass and intertidal sand and mud flats have not yet been estimated.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	1244	25	n/a[c]	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; c= mapping currently in progress; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Vanuatu, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	-5 to -20	-5 to -30	-10 to -35

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

All categories of coastal fisheries in Vanuatu are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	0	-10	-15 to -20	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna dominate the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the expected decrease in productivity of all components of the fishery. As a result, potential catches from coastal fisheries in Vanuatu are projected to decrease slightly under both scenarios in 2035, and continue to decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	51	-3.5	-2	-20	-10	-35	-18
Nearshore pelagic fish	23	0	0	-10	-2	-17.5	-4
Targeted invertebrates	2	-3.5	-0.07	-10	-0.2	-20	-0.4
Inter/subtidal invertebrates	24	0	0	-5	-1	-10	-2
Total catch[a]			**-2**		**-14**		**-25**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Vanuatu; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

Recent catch and value

The main freshwater and estuarine species caught in Vanuatu include flagtails (jungle perch), grunter, freshwater snappers, silver biddies, silver moonfish, scats, mullet, carp, tilapia and *Macrobrachium*. These species are taken mostly by subsistence fisheries. The estimated annual freshwater fish catch in Vanuatu in 2007 was 80 tonnes, worth USD 173,000 {Chapter 10}.

Existing freshwater and estuarine fish habitat

The larger rivers in Vanuatu provide a diversity of freshwater and estuarine fish habitats to support fish communities {Chapter 7, Table 7.1}.

Island	Largest river	Catchment area (km^2)	River length (km)
Espiritu Santo	Jourdain	369	53
Efate	Teouma	91	28

Projected changes to freshwater and estuarine fish habitat

The projected increase in rainfall for Vanuatu {Chapter 2, Section 2.5.2} is expected to result in increases in the area and quality of all freshwater fish habitats. The greatest increases in freshwater habitats are expected to occur under A2 in 2100 {Chapter 7, Table 7.5}. Sea-level rise is expected to increase the area of estuarine habitat {Chapter 7}.

Projected changes to freshwater and estuarine fish habitat area (%)		
B1/A2 2035	B1 2100*	A2 2100
-5 to +10	-5 to +5	+5 to +10

* Approximates A2 in 2050.

Projected changes in freshwater and estuarine fisheries production

Higher projected rainfall and river flows are not expected to influence production from freshwater and estuarine fisheries in Vanuatu until 2100 under A2, when the availability and quality of habitats are estimated to increase, providing better fish migration cues, and enhancing reproduction and recruitment. These changes are expected to increase freshwater catch by ~ 7.5% {Chapter 10, Section 10.5}.

Projected changes in freshwater and estuarine fish catch (%)		
B1/A2 2035	B1 2100*	A2 2100
0 to +2.5	0	+7.5

* Approximates A2 in 2050.

Aquaculture

Recent and potential production

The main aquaculture commodities in Vanuatu include those produced for livelihoods in coastal waters such as shrimp, marine ornamentals (coral fragments and giant clams), marine fish and trochus. Tilapia and *Macrobrachium* are also produced by freshwater aquaculture for food security.

Aquaculture commodity	Annual production (tonnes)	Annual value (USD)
Shrimp	17	426,400
Tilapia[a]	80	n/a

* 2006–2008 data; a = produced in cages in a freshwater lake; n/a = data not available.

Existing and projected environmental features

Changing rainfall patterns and increasing air and sea temperatures are eventually expected to alter some of the present favourable conditions for coastal aquaculture in Vanuatu {Chapter 11}. Increasing SST, ocean acidification and the possibility of stronger cyclones are expected to reduce the survival and growth of shrimp, ornamental species, marine fish and trochus. In addition, sea-level rise is expected to affect the drainage of shrimp ponds. Higher rainfall and air temperatures are likely to improve the growth of tilapia {Chapter 11}.

Environmental feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	24.2[a]	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Annual rainfall (mm)	2118[a]	-5 to -10%	-5 to -20%	-5 to -20%	-5 to -20%
Cyclones (no. per year)	2.6	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Sea surface temperature (°C)	27.1	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3

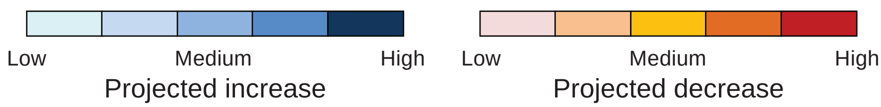
* Approximates A2 in 2050; a = data for Efate.

Projected changes in aquaculture production

In the short term, higher air temperatures are expected to improve shrimp growth and reduce cold season impacts, resulting in greater yields per hectare in the medium term. However, by 2100, increasing summer temperatures and changing rainfall patterns are likely to reduce shrimp growth rates and increase the incidence of disease. Freshwater aquaculture production is expected to be enhanced by climate change, provided ponds are located where they will not be affected by floods or storm surge {Chapter 11, Table 11.5}.

Aquaculture commodity	Use	Projected change		
		B1/A2 2035	B1 2100*	A2 2100
Tilapia	Food security	↑	↑	↑
Shrimp	Livelihoods	↑	↓	↓
Marine ornamentals	Livelihoods	↓	↓	↓
Macrobrachium	Livelihoods	↑	↓	↓
Marine fish	Livelihoods	↓	↓	↓
Trochus	Livelihoods	↓	↓	↓

* Approximates A2 in 2050.



Economic and social implications

Economic development and government revenue

Current contributions

Licence fees from foreign purse-seine and longline vessels contributed 1.7% and 0.2% to government revenue (GR), respectively, in 2007. The industrial tuna fishery in Vanuatu did not contribute to gross domestic product (GDP) in 2007 {Chapter 12}. However, on-shore activities have commenced to add value to longline catches since then.

Industrial fishery	Contribution to GR*	
	USD m	GR (%)
Surface[a]	1.4	1.7
Longline[b]	0.2	0.2

* Information for 2007, when total GR was USD 79 million; a = locally-based purse-seine; b = information from 1999.

Projected effects of climate change

The projected range of changes to government revenue due to the effects of climate change on the distribution and abundance of tuna are relatively minor due to the small contribution made by the industrial tuna fishery to the economy of Vanuatu {Chapter 12}.

Food security

Vanuatu is among the group of PICTs (Group 3) where the estimated sustainable production of fish and invertebrates from coastal habitats is unable to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i] {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Vanuatu is estimated to be 20 kg per person per year[2] , well below the recommended levels for good nutrition. At present, coral reefs in Vanuatu are estimated to be able to supply only 16 kg of fish per person per year.

Fish consumption per person (kg)			Animal protein from fish (%)		Fish provided by subsistence catch (%)	
National	Rural	Urban	Rural	Urban	Rural	Urban
20	21	19	60	43	60	17

Effects of population growth

Vanuatu will have a rapidly increasing total demand for fish for food security due to the predicted growth in population. Therefore, the current estimated shortfall between the fish needed for food security and the estimated fish production from coral reefs of 19 kg per person per year, increases to 25 kg in 2035, 27 kg in 2050 and 29 kg in 2100.

Variable	2010	2035	2050	2100
Population (x 1000)	252	400	483	695
Fish available per person (kg/year)[a]	16	10	8	6
Gap (kg/person/year)[b]	19	25	27	29

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

Vanuatu faces further declines in the fish available per person due to the combined effects of population growth and climate change. By 2050, the projected declines in production of demersal fish associated with coral reefs is expected to cause the gap

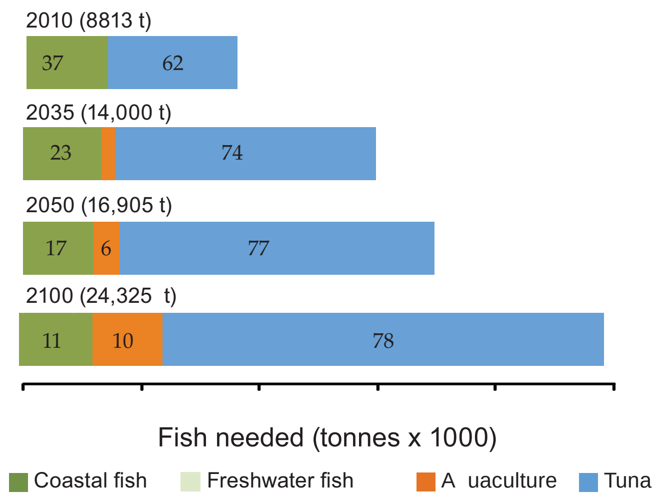
i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

between the fish needed per person for good nutrition, and the fish available from coral reefs, to increase from 27 to 28 kg per person per year under the A2 emissions scenario. The gap is expected to widen from 29 to 31 kg per person per year by 2100.

Filling the gap

Tuna is the main resource available to Vanuatu for supplying the large shortfall in fish needed for food security from coastal habitats. This gap will need to be filled mostly by tuna and bycatch species because freshwater fisheries and freshwater aquaculture are only expected to be able to provide limited quantities of fish, although aquaculture could make up 11% of the fish required by 2100.

The implication is that an increasing proportion of the annual average tuna catch will need to be allocated over time to provide the quantities of fish recommended for good nutrition of Vanuatu's population. The proportion of the total amount of fish needed for food security to be provided by tuna is 74% in 2035, 77% in 2050, and 78% in 2100.



Fish (in tonnes) needed for future food security in Vanuatu, and the recommended contributions (%) of fisheries resources and aquaculture production required to meet future needs.

Livelihoods

Current contributions

Full-time and part-time jobs have been created through tuna fishing and processing in Vanuatu, although they represent only a low percentage of total employment in the nation. Coastal fisheries also provide important opportunities to earn income for coastal communities throughout the country, with > 60% of households in representative coastal communities deriving their first or second income from catching and selling fish. Aquaculture has created 30 jobs[4].

Jobs on tuna vessels*			Jobs in shore-based tuna processing			Coastal households earning income from fishing (%)			Jobs in aquaculture**
2002	2006	2008	2002	2006	2008	1st	2nd	Both	2007
54	20	30	30	30	30	21	40	61	30

* In 2009, ~ 400 Ni-Vanuatu were employed on nationally-flagged tuna fishing vessels; ** Ponia (2010)[4]; information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries, the nearshore component of coastal fisheries and pond aquaculture. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario				
	Oceanic fisheries**	Coastal fisheries		Aquaculture	
		Nearshore pelagic fish	Other resources	Ponds	Coastal
Present*	⇧	⇧	⇩	⇧	⇧
2035	↑	No effect	↓	↑	↓
2050	No effect	↓	↓	↑	↓
2100	↓	↓	↓	↑	↓

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches; freshwater and estuarine fisheries not included due to their subsistence role.

Percentage increase Percentage decrease

Adaptations and suggested policies

The plans Vanuatu has to derive greater socio-economic benefits from fisheries and aquaculture will depend heavily on interventions to:

1. maximise access to tuna, and the efficiency of fishing operations, to provide fish for economic development and continued food security;
2. manage coastal fish habitats and fish stocks to minimise the gap between the fish available from coral reefs and the fish needed for food security; and
3. increase the number of livelihoods that can be based on fishing, tourism and aquaculture.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E3	Immediate conservation management measures for bigeye tuna	E7, E8
E4	Energy efficiency programmes for industrial tuna fleets	E9
E5	Environmentally-friendly fishing operations	
E7	Safety at sea	E10
E8	Climate-proof infrastructure	E11
E9	Pan-Pacific tuna management	E2

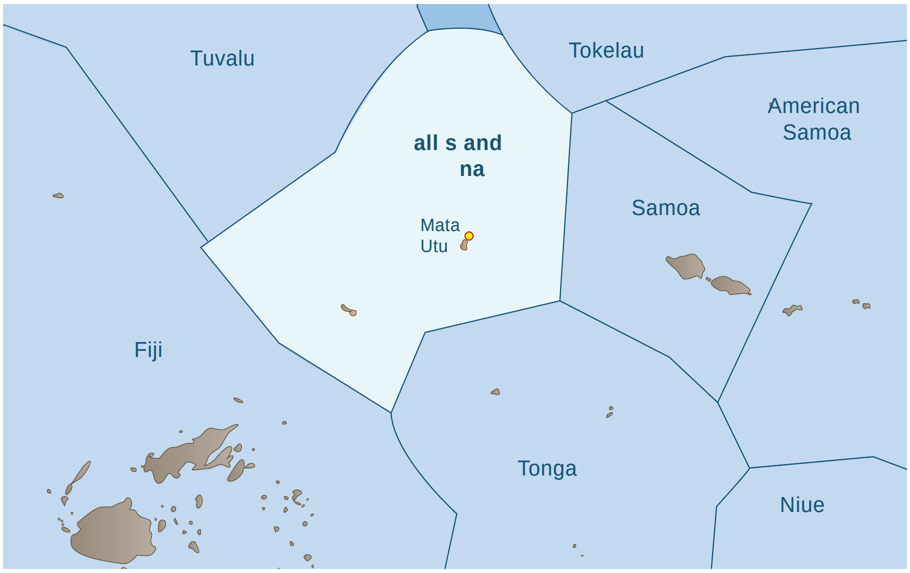
Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F4	Allow for expansion of freshwater habitats	F4, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F7	Manage freshwater and estuarine fisheries to harness opportunities	
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	F13–16, F18
F10	Develop coastal fisheries for small pelagic fish	F13, F17, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	**Summary of adaptation**	**Supporting policy no. (Section 3.7)**
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3
L4	Diversify production of coastal aquaculture commodities	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L6

2.22 Wallis and Futuna



Key features

Population

Year	2010	2035	2050	2100
Population (x 1000)[a]	13	14	14	14
Population growth rate[a]	-0.6	0	0	0

a = Data from SPC Statistics for Development Programme (www.spc.int/sdp).

EEZ area (km²) 242,445

Land area (km²) 255

Land as % of EEZ 0.1

Fisheries and aquaculture activities: Oceanic fisheries and coastal fisheries.

Membership of regional fisheries management arrangements: Western and Central Pacific Fisheries Commission (participating territory).

Surface climate and the ocean

Existing features

Wallis and Futuna has a tropical climate {Chapter 2}. Recent air temperatures in Hihifo have averaged 27.1°C and average rainfall is ~ 3340 mm per year. Wallis and Futuna lies within the South Pacific Subtropical Gyre Province (SPSG) {Chapter 4, Figure 4.6}. The SPSG Province is created by anticyclonic atmospheric circulation and rainfall in the centre of the province is low. The rotation of the gyre deepens the vertical structure of the water column, making the surface waters nutrient poor {Chapter 4}.

Projected changes to surface climate

Air temperatures and rainfall in Wallis and Futuna are projected to increase due to climate change under the low (B1) and high (A2) emissions scenarios in 2035 and 2100 {see Chapter 1, Section 1.3 for definition of scenarios} relative to long-term averages {Chapter 2, Section 2.5, Table 2.6}.

Climate feature[a]	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)	27.1 (Hihifo)	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall (mm)	3339 (Hihifo)	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
		More extreme wet and dry periods			
Cyclones (no. per year)	1.6	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			

* Approximates A2 in 2050; a = for more detailed projections of rainfall, air temperature and cyclones in the vicinity of Wallis and Futuna, see www.cawcr.gov.au/projects/PCCSP.

Projected changes to the ocean

The projected changes to the key features of the tropical Pacific Ocean surrounding Wallis and Futuna relative to the long-term averages are expected to result in increases in sea surface temperature (SST), sea level and ocean acidification. Changes to ocean currents (increases in the South Pacific gyre) and reductions in nutrient supply are also expected to occur {Chapter 3, Sections 3.3 and 3.4, Tables 3.1 and 3.2}.

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	28.9[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Oceanic fisheries

Recent catch and value

There is a locally-based longline vessel fishing for tuna in the exclusive economic zone (EEZ) of Wallis and Futuna. Between 1999 and 2008 foreign vessels caught an average of 168 tonnes of tuna (mainly albacore) per year from the EEZ, worth USD 400,000. See 'Coastal Fisheries' below for contributions of tuna to nearshore artisanal and small-scale commercial fisheries.

Existing oceanic fish habitat

Wallis and Futuna's EEZ lies within the generally nutrient-poor waters of the SPSG Province {Chapter 4, Figure 4.6}. This province is characterised by downwelling and low nitrate concentrations in deeper waters. Net primary production is low, particularly in summer when there is the formation of a marked thermocline {Chapter 4, Section 4.4.3}. Local upwelling around islands can result in small areas of enriched surface productivity. In general, however, the SPSG Province does not provide prime feeding areas for tuna.

Projected changes to oceanic fish habitat

Under climate change, the surface area of the SPSG Province is projected to increase and extend poleward. Key components of the food web (net primary production and zooplankton biomass) are expected to decrease in SPSG {Chapter 4, Table 4.3}.

SPSG feature	Projected change (%)			
	B1 2035	A2 2035	B1 2100*	A2 2100
Surface area[a]	+4	+7	+7	+14
Location	Poleward extension of southern limit			
Net primary production	-3	-5	-3	-6
Zooplankton biomass	-3	-4	-5	-10

* Approximates A2 in 2050; a = area derived from modelling of nutrients and salinity {Chapter 4, Table 4.3}.

Projected changes in oceanic fisheries production

Preliminary modelling suggests that under the B1 and A2 emissions scenarios, catches of skipjack tuna in the EEZ of Wallis and Futuna are expected to increase significantly in 2035 and 2100, relative to the 20-year average (1980–2000). Catches of bigeye tuna are projected to remain stable under both scenarios in 2035 and B1 in 2100, and to decrease under A2 in 2100 {Chapter 8, Section 8.7}. Modelling for yellowfin tuna and albacore is now in progress. The trends for yellowfin are expected to be similar to those for skipjack tuna, whereas albacore are expected to move poleward and to be more abundant at the edges of the SPSG Province.

Projected change in skipjack tuna catch (%)			Projected change in bigeye tuna catch (%)		
B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
+44	+49	+46	0	0	-7

* Approximates A2 in 2050.

Coastal fisheries

Recent catch and value

The coastal fisheries of Wallis and Futuna are made up of four components: demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish (including tuna, rainbow runner, wahoo and mahi-

mahi), invertebrates targeted for export, and invertebrates gleaned from intertidal and subtidal areas {Chapter 9, Section 9.2.1}. The total annual catch was estimated to be ~ 960 tonnes in 2007, worth USD 7.5 million. The commercial catch was ~ 120 tonnes. Demersal fish are estimated to make up 75% of the total catch.

Feature	Coastal fisheries category				Total	Total value (USD m)*
	Demersal fish	Nearshore pelagic fish[b]	Targeted invertebrates	Inter/subtidal invertebrates		
Catch (tonnes)*	718	106	17	120	961	7.5
Contribution (%)[a]	75	11	2	12	100	

* Estimated total catch and value in 2007 (Gillett 2009)[1]; a = method for calculating disaggregated catch data for each category is outlined in Chapter 9 {Appendix 9.2, Supplementary Table 9.1}; b = catch dominated by non-tuna species.

Existing coastal fish habitat

Wallis and Futuna has > 900 km^2 of coral reefs to support coastal fisheries species {Chapter 5}. Other fish habitats include deepwater and intertidal seagrasses, mangroves and intertidal sand flats {Chapter 6}.

Habitat	Coral reef[a]	Mangrove[b]	Seagrass[b]	Intertidal flat
Area (km^2)	932	0.2	24	n/a

a = Includes barrier, patch and fringing reefs and reef lagoons {Chapter 5, Table 5.1}; b = values from Chapter 6, Table 6.1; n/a = data not available.

Projected changes to coastal fish habitat

Climate change is expected to add to existing local threats to coral reefs, mangroves, seagrasses and intertidal flats in Wallis and Futuna, resulting in declines in the quality and area of all habitats {Chapters 5 and 6}.

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-10	-50	-60
Seagrass area	-5 to -20	-5 to -35	-10 to -50

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

Projected changes in coastal fisheries production

Fisheries for demersal fish, targeted invertebrates and intertidal and subtidal invertebrates in Wallis and Futuna are projected to show progressive declines in productivity due to both the direct effects (e.g. increased SST) and indirect effects (changes to fish habitats) of climate change {Chapter 9, Section 9.5}. On the other hand, the nearshore pelagic fishery component of coastal fisheries is projected to increase in productivity due to the redistribution of tuna to the east {Chapter 8}.

Coastal fisheries category	Projected change (%)			Main effects
	B1/A2 2035	B1 2100*	A2 2100	
Demersal fish	-2 to -5	-20	-20 to -50	Habitat loss and reduced recruitment (due to increasing SST and reduced currents)
Nearshore pelagic fish[a]	+15 to +20	+20	+10	Changes in distribution of tuna
Targeted invertebrates	-2 to -5	-10	-20	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Inter/subtidal invertebrates	0	-5	-10	Declines in aragonite saturation due to ocean acidification

* Approximates A2 in 2050; a = tuna contribute to the nearshore pelagic fishery {Chapter 9, Tables 9.8 and 9.10}.

The overall projected change to coastal fisheries catch reflects the strong reliance on demersal fish and the projected decrease in productivity of most coastal fishery components. As a result, total catches from coastal fisheries in Wallis and Futuna are projected to decrease slightly under both scenarios in 2035, and continue to decline under both scenarios in 2100, particularly under A2 in 2100.

Coastal fisheries category	Contrib. (%)**	Projected change in productivity (P) and catch (%)					
		B1/A2 2035		B1 2100*		A2 2100	
		P***	Catch	P***	Catch	P***	Catch
Demersal fish	75	-3.5	-3	-20	-15	-35	-26
Nearshore pelagic fish	11	+17.5	+2	+20	+2	+10	+1
Targeted invertebrates	2	-3.5	-0.06	-10	-0.2	-20	-0.4
Inter/subtidal invertebrates	12	0	0	-5	-0.6	-10	-1
Total catch[a]			**-0.8**		**-13.5**		**-27**

* Approximates A2 in 2050; ** contribution of each component to total coastal fisheries catch in Wallis and Futuna; *** median projected change in productivity based on range in Chapter 9; a = assumes that proportion of each category remains constant.

Freshwater and estuarine fisheries

There are no freshwater and estuarine fisheries in Wallis and Futuna (with the exception of some capture of *Macrobrachium*).

Aquaculture

There is no aquaculture production in Wallis and Futuna (altough the potential for growing rabbitfish in cages and sea ranching sandfish is to be investigated)

Economic and social implications

Economic development and government revenue

One locally-based tuna longline vessel has recently started operating in the EEZ of Wallis and Futuna but has not yet contributed to gross domestic product or government revenue.

Food security

Wallis and Futuna is among the group of PICTs (Group 2) where the estimated sustainable production of fish and invertebrates from coastal habitats has the potential to supply the national population with the 35 kg of fish per person per year recommended for good nutrition[i]. However, it may be difficult to distribute the catch from some reefs in the EEZ due to the distances between these fishing areas and population centres {Chapter 12, Section 12.7.1}.

Current contributions of fish to food security

Average national fish consumption in Wallis and Futuna is estimated to be 75 kg per person per year[2], well above the recommended levels for good nutrition. At present, coral reefs in Wallis and Futuna are estimated to be able to supply 213 kg of fish per person per year.

Fish consumption per person (kg)			Fish provided by subsistence catch (%)	
National	Rural	Urban	Rural	Urban
74	n/a	n/a	86	86

n/a = Data not available.

i Based on fish contributing 50% of dietary protein as recommended by the SPC Public Health Programme (SPC 2008)[25].

Effects of population growth

The population in Wallis and Futuna is predicted to remain stable over this century and coastal fisheries are expected to meet the demand for fish for food security. The current estimated surplus of fish required for good nutrition is expected to continue to be available until 2100.

Variable	2010	2035	2050	2100
Population (x 1000)	13	14	14	14
Fish available per person (kg/year)[a]	213	206	206	206
Surplus (kg/person/year)[b]	178	171	171	171

a = Based on 3 tonnes of fish per km^2 of coral reef habitat {Chapter 9}; b = relative to recommended consumption of 35 kg per person per year.

Additional effects of climate change

The projected decrease in production of demersal fish of up to 50% by 2100 under the A2 emissions scenario is not expected to significantly affect the fish available per person for food security in Wallis and Futuna. The large area of coral reefs relative to population size will continue to have potential to supply sufficient coastal fish to meet the traditionally high levels of fish consumption, provided the fish can be distributed from distant reefs to the islands, particularly to Futuna.

Livelihoods

Current contributions

Coastal fisheries provide important opportunities to earn income for coastal communities in Wallis and Futuna, with more than 40% of representative coastal households deriving their first or second income from catching and selling fish.

Coastal households earning income from fishing (%)		
1st	2nd	Both
21	23	44

Information derived from Chapter 12, Table 12.6 and the SPC PROCFish Project.

Projected effects of climate change

The effects of climate change on the potential to create more livelihoods based on fisheries and aquaculture are difficult to estimate because there is still scope to derive new jobs from oceanic fisheries and the nearshore component of coastal fisheries. However, the A2 emissions scenario is expected to eventually enhance or retard these opportunities as indicated below.

Year	Projected change under A2 scenario		
	Oceanic fisheries**	Coastal fisheries	
		Nearshore pelagic fish	Other resources
Present*	⇧	⇧	⇩
2035	⬆	⬆	⬇
2050	⬆	⬆	⬇
2100	⬆	⬆	⬇

* Indicates general direction of new opportunities for livelihoods based on the activity; ** based on projected changes in skipjack tuna catches.

Percentage increase Percentage decrease

Adaptations and suggested policies

The plans Wallis and Futuna has to derive greater socio-economic benefits from fisheries will depend heavily on interventions to:

1. manage coastal fish habitats and fish stocks to ensure that they continue to provide fish for food security;
2. increase access to tuna for coastal fishers to diversify the supply of fish for food; and
3. increase the number of livelihoods that can be based on fishing and tourism.

The adaptations and suggested policies to achieve these plans under a changing climate are summarised below (see Section 3 for details).

Economic development and government revenue

Adaptation no. (Section 3.2)	Summary of adaptation	Supporting policy no. (Section 3.3)
E3	Immediate conservation management measures for bigeye tuna	E8
E7	Safety at sea	E10
E9	Pan-Pacific tuna management	E2

Food security

Adaptation no. (Section 3.4)	Summary of adaptation	Supporting policy no. (Section 3.5)
F1	Manage and restore vegetation in catchments	F1, F2, F18
F2	Foster the care of coastal fish habitats	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	F4, F5, F18
F5	Sustain production of coastal demersal fish and invertebrates	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	F6, F13, F18
F8	Increase access to tuna for urban and rural populations	F8–F13, F18
F11	Improve post-harvest methods	F17, F18

Sustainable livelihoods

Adaptation no. (Section 3.6)	Summary of adaptation	Supporting policy no. (Section 3.7)
L1	Improve technical and business skills of communities	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L2
L3	Develop coral reef ecotourism ventures	L3

3. Adaptations and supporting policies

3.1 Choosing the best adaptations

The adaptations required to reduce the threats of climate change to the important contributions made by fisheries and aquaculture to PICTs, and capitalise on the opportunities, should also address the other key drivers affecting the sector. These include population growth, urbanisation, governance and political stability, status of fisheries resources in other oceans, technological innovation, markets and trade and fuel costs. Population growth and urbanisation are expected to be particularly significant, especially in Melanesia {Chapters 1 and 12}.

Most of these drivers have the potential to affect fisheries and aquaculture before the projected effects of climate change become limiting. A framework is needed for planned adaptations that addresses the other drivers in the near term, and climate change in the longer term. The best adaptations will be those that deliver both short-term and long-term benefits ('win-win' adaptations) (Figure 3.1).

Adapting to climate change will also involve some 'lose-win' adaptations – where the economic and social costs are relatively high initially, but where investments position PICTs to receive net benefits in the longer term. 'Win-lose' investments represent maladaptation to climate change and should be avoided, except in extreme cases where human survival may otherwise be compromised.

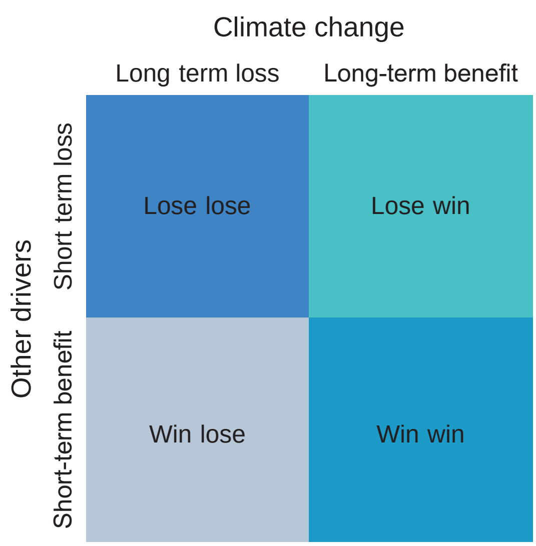


Figure 3.1 Decision framework for identifying adaptations to address climate change and other drivers (source: Grafton 2010)[24].

Identification of win-win and lose-win adaptations should not be based simply on the projected future responses of the resources underpinning fisheries and aquaculture. There are potential social barriers to the uptake of appropriate technology {Chapter 13}. Examples of such barriers include the cultural norms and gender issues that may limit broad-based community participation. The probability of removing these barriers to provide communities with a wider range of strategies to adapt to climate change must also be assessed when evaluating the likely success of proposed adaptations.

In this section, we provide details of the win-win and lose-win adaptations needed to maximise sustainable benefits from fisheries and aquaculture for economic development and government revenue, food security, and livelihoods as the climate changes. Each set of adaptations is followed by a list of the policies needed to support them.

3.2 Adaptations for economic development and government revenue (E)

The projected eastward shift in the distribution of skipjack tuna {Chapter 8}, and ultimately fishing effort, is expected to have two important implications for gross domestic product (GDP) and government revenue. First, it should increase the contribution of licence fees from DWFNs to those PICTs in the central Pacific (Kiribati, Nauru, Tokelau and Tuvalu) that already rely heavily on these fees for government revenue. Larger catches of tuna further east should also increase the contribution of fishing to GDP in American Samoa and Marshall Islands, and perhaps create new opportunities for economic development in Polynesia {Chapter 12}. Second, it could affect plans to expand national industrial fishing and processing operations to increase benefits from tuna resources in some PICTs in the western part of the region, particularly PNG and Solomon Islands. However, while potential decreases in contributions of fishing and processing operations to GDP and government revenue from licence fees may occur for countries in the west, the implications should not be profound in PNG due to the relatively large size of its economy {Chapter 12}. The effects are expected to be greater in Solomon Islands, where industrial fishing and processing presently contributes ~ 5% to GDP and where more canneries are planned {Chapter 12}.

The adaptations and suggested policies to maximise the economic benefits from oceanic fisheries for PICTs in the central and eastern Pacific, and to minimise the impacts for PICTs in the west, are outlined below. These adaptations involve (1) development of flexible management measures to allow fishing effort to shift east, while ensuring that large quantities of tuna can still be channeled through the established and proposed canneries in the west; and (2) optimising the productivity of tuna resources across the region.

➢ **Adaption E1: Full implementation of sustainable fishing effort schemes (win-win)**

The vessel day scheme (VDS) for the purse-seine fishery, which allocates fishing effort among the EEZs of the eight countries that are the Parties to the Nauru Agreement (PNA), provides an important means of accommodating the effects of El Niño-Southern Oscillation (ENSO) events on the distribution of tuna now and in the future. The VDS for each fishery is intended to hold total fishing effort for PNA members constant, yet allow them to trade fishing days when the fish are concentrated either in the west or east due to ENSO events. The VDS is designed to operate in a similar way to the 'cap and trade' systems proposed to limit emissions of carbon dioxide (CO_2) and ensures that all PNA members continue to receive some level of benefits, regardless of where tuna are concentrated. For the VDS to work efficiently, however, PNA countries will need to develop the capacity and governance to ensure that fishing effort conforms to the specified levels. Allocation of effort among members will also need to be adjusted periodically, as provided for under the VDS, as tuna stocks move progressively east. Periodic adjustment will still allow the transfer of effort during ENSO events well into the future, but avoid the need for PNA members further to the east to continually purchase vessel days from those in the west, based on present-day catches.

A VDS is also being developed by PNA for the longline fishery but is likely to be more challenging to implement because of the larger number of vessels involved, the difficulties in providing observers for vessels and the lower value of the fishery. The sustainable fishing effort scheme for albacore and other species of tuna being developed by members of the Te Vaka Moana Arrangement in southern subtropical waters should also be a practical way of adapting to any changes in the distributions of these species.

➢ **Adaptation E2: Diversify sources of fish for canneries (win-win)**

The Interim Economic Partnership Agreements (IEPA) between Papua New Guinea (PNG) and the European Union (EU), and Fiji and the EU, assist these PICTs to develop their fish processing operations in the near term by paving the way for exports to Europe in the face of strong competition from canneries in Asia. The 'global sourcing provision' of the IEPA is particularly advantageous because it enables a country to acquire and export fish from any other country. Obtaining a full Economic Partnership Agreement (EPA) for the long term is of great importance to PNG so that the nation can secure supplies of fish for its canneries as tuna are redistributed further east. It is also in the strong interest of Solomon Islands to sign an IEPA with the EU, given the plans underway to build additional canneries in that country. Papua New Guinea, Fiji and Solomon Islands should continue to take an active role in the negotiations for interim and full economic partnership agreements to ensure that the global sourcing provision and other development incentives included in these agreements are available for many years.

An important proviso, however, is that any PICTs supplying fish to PNG for the European market will need to comply with (1) EU food safety requirements by establishing a fishery product food safety competent authority and the associated laboratory testing facilities; and (2) illegal, unreported and unregulated (IUU) fishing regulations by setting up a system of certification and product tracking to demonstrate that fish were caught legally.

Other adaptations that should help maintain continuity in the supply of fish for canneries in PNG and Solomon Islands during El Niño episodes in the short term, and under the projected effects of climate change on tuna in the long term, include (1) reducing access for DWFNs to their EEZs to provide more fish for national vessels; (2) requiring DWFNs operating within their EEZs to land a proportion of catches for use by local canneries; (3) enhancing existing arrangements for their national fleets to fish in the EEZs of other PICTs; and (4) creating any additional incentives necessary for tuna caught in other EEZs to be landed in their ports. These adaptations would need to be integrated with the provisions of the VDS and IEPA/EPA.

➢ Adaptation E3: Immediate conservation management measures for bigeye tuna (lose-win)

Addressing the current overfishing of bigeye tuna in the Western and Central Pacific Ocean (WCPO) {Chapter 8} by reducing fishing mortality should help rebuild the population to a level that is expected to assist this species adapt to the projected changes to the tropical Pacific Ocean {Chapters 3 and 4}. The benefits of management measures to reduce fishing mortality are not expected to be fully effective for 10–20 years because bigeye tuna is a relatively long-lived species (> 12 years).

➢ Adaptation E4: Energy efficiency programmes for industrial fleets (win-win)

Energy audits to identify how to reduce the use of fuel for routine fishing operations, followed by energy efficiency programmes to implement these savings, should increase the economic efficiency of fleets in both the near and long term. These initiatives should assist industrial fleets to cope with fluctuations in oil prices, and reduce the costs for national vessels from Federated States of Micronesia (FSM), PNG and Solomon Islands of fishing further afield as the distribution of tuna shifts to the east. Although purse-seine vessels use less fuel per tonne of fish caught than longliners, this adaptation is still expected to result in significant reductions in operating costs for purse-seiners.

To reduce the effects of future increases in international oil prices, locally-based industrial fishing fleets in Melanesia should evaluate the economic, social and environmental benefits of coconut oil and other biofuels to ascertain whether they are a viable alternative energy source. Some coastal shipping vessels in PNG have already made the transition to locally produced biofuels and further uptake is expected once the lubrication qualities of these fuels are improved.

➢ Adaptation E5: Environmentally-friendly fishing operations (win-win)

Identifying how to reduce any effects of existing tuna fishing operations, and those projected to occur as the distribution of tuna moves to the east, on non-target and dependent species should assist PICTs to meet the requirements of certification schemes to promote responsible fishing practices. Finding ways to (1) reduce CO_2 emissions from commercial fishing fleets (outlined above) and canneries to ensure that tuna from the region is competitive in carbon labelling schemes; and (2) replace steel cans with alternative forms of packaging, should also help maintain access to markets for tuna as global pressure to minimise the carbon footprint of fishing and processing operations increases.

➢ Adaptation E6: Gender-sensitive fish processing operations (win-win)

The efficiency and productivity of existing and planned tuna canneries and loining plants in PNG, Solomon Islands and elsewhere in the region rely heavily on women for their labour force. Efficiency and productivity are likely to be improved by ensuring that the rights and responsibilities of Pacific women are recognised in their employment conditions, and that they have the appropriate training and opportunities to undertake managerial roles. Management that is sensitive to culture and gender provides a potential win-win adaptation because it should enhance the loyalty of staff, even when climate change imposes stresses on households.

➢ Adaptation E7: Safety at sea (win-win)

Although the weather forecasts available to tuna fleets in the region will continue to improve, safety audits should be conducted to ensure that longline vessels (and any purse-seine vessels) operating within the cyclone belt {Chapter 2} can achieve acceptable standards for safety at sea in the event that more severe cyclones occur. This adaptation will help protect fishing crews both now and in the future.

➢ Adaptation E8: Climate-proof infrastructure (lose-win)

New infrastructure built to support fishing fleets, canneries and loining plants should be constructed in locations that will not be inundated by rising sea levels projected to occur during the expected life spans of such facilities {Chapter 3}. At latitudes higher than ~ 10°S–10°N, infrastructure should also be built to withstand the possible effects of more severe cyclones {Chapter 2}. Investments may also be needed to modify existing infrastructure for industrial fishing operations and processing facilities. The planning and expenditure involved in climate-proofing infrastructure for the fisheries sector may reduce profits in the shorter term, but enable operations to continue in the longer term.

➢ Adaptation E9: Pan-Pacific tuna management (lose-win)

The projected progressive shift of tuna from the WCPO to the east may eventually require cooperation in all aspects of tuna fisheries management between the WCPFC and the Inter-American Tropical Tuna Commission (IATTC). A merger of these organisations to form a pan-Pacific tuna fisheries management agency is something that may eventually need to be considered (providing the relative effort by vessels from the WCPO and Eastern Pacific Ocean is maintained). The costs of any such re-organisation are likely to exceed the advantages initially, but the benefits are expected to outweigh these costs as the distributions of tuna species change.

3.3 Supporting policies for economic development and government revenue (E)

The suggested policies required to implement the adaptations to maintain or improve the contributions from oceanic fisheries to economic development and government revenue described in Section 3.2 are outlined below. The policies that apply to each adaptation are listed in Table 3.1.

- **Policy E1: Promote transparent access agreements** between PICTs and DWFNs so that the VDS allocations, in particular, can be easily understood by all PNA members (and non-PNA countries which purchase fishing days from PNA members under bilateral arrangements and have vessels fishing in PNA waters). Strengthen national capacity to recognise successes and failures in VDS arrangements (and other fishing effort schemes), and the governance needed to administer the VDS, so that this fishing effort scheme fulfils its potential.
- **Policy E2: Explore further approaches to collective management** to see whether they can boost national capacity to implement measures that will continue to strengthen national economies and conserve tuna stocks.
- **Policy E3: Adjust national tuna management plans and marketing strategies** to provide more flexible arrangements to sell tuna, or acquire tuna needed for national processing operations. Depending on the country, this policy may involve securing a long-term EPA with the EU, establishing a fishery product food safety competent authority and associated laboratory testing facilities or services, and demonstrating that catches comply with IUU fishing regulations. Additional markets to the EU should also be developed.
- **Policy E4: Include implications of climate change in the development of future management objectives and strategies for the Western and Central Pacific Fisheries Commission (WCPFC)**, particularly in relation to the projected eventual reduction in overall abundance of skipjack, yellowfin and bigeye tuna in the WCPO. In particular, WCPFC should consider the need to (1) strengthen the mechanisms to manage total fishing effort or catches (or both) in its convention area; and (2) develop the necessary tools to monitor and enforce its conservation and management measures to anticipate any large change in the fundamental biological parameters of exploited stocks.

- **Policy E5: Revise licensing conditions for DWFNs, as needed, to require that all vessels provide operational-level catch and effort data** from log sheets (including historical data) for fish caught both within the EEZ and on the high seas. The data should be submitted to the licensing country for subsequent use by WCPFC and SPC to improve the models for estimating tuna distributions and catches in the future (Section 5).
- **Policy E6: Finalise the declaration of national ocean boundaries** in compliance with the United Nations Convention on the Law of the Sea. For many countries, this involves completing the technical work to establish their baselines (terrestrial base reference points).
- **Policy E7: Apply regionally-responsible, spatially-explicit national management measures** to address the implications of climate change for subregional concentrations of tuna in national archipelagic waters beyond the mandate of WCPFC.
- **Policy E8: Develop further measures to mitigate the capture of bigeye tuna** by purse-seine as climate-driven redistribution of this species occurs to the east, where purse-seine catch per unit effort is much higher.
- **Policy E9: Use regional trade and preferential access agreements to market environmentally-friendly tuna products** based on responsible fishing methods, equitable processing operations, and distribution channels that minimise CO_2 emissions throughout the supply chain.
- **Policy E10: Ensure all industrial fishing operations meet accepted standards for safety at sea**, by including any changes in design or equipment needed to make longline and purse-seine vessels more seaworthy during cyclones in fishing licences.
- **Policy E11: Require all new infrastructure to be more climate-proof**, by ensuring that (1) land-based facilities are not constructed where they could be inundated by rising sea levels or exposed to any projected increase in storm surge during the expected term of the investment; and (2) wharfs and access roads continue to function as sea level rises, and if cyclones increase in intensity.

Table 3.1 Summary of adaptations and companion supporting policies to maintain or improve the contributions of oceanic fisheries to economic development and government revenue for Pacific Island countries and territories (see Sections 3.2 and 3.3 for details).

Adaptation		Type	Supporting policy*
E1	Full implementation of sustainable fishing effort schemes	W-W	E1, E2, E4–E6
E2	Diversify sources of fish for canneries	W-W	E1–E5, E7
E3	Immediate conservation management measures for bigeye tuna	L-W	E7, E8
E4	Energy efficiency programmes for industrial tuna fleets	W-W	E9
E5	Environmentally-friendly fishing operations	W-W	
E6	Gender-sensitive fish processing operations	W-W	
E7	Safety at sea	W-W	E10
E8	Climate-proof infrastructure	L-W	E11
E9	Pan-Pacific tuna management	L-W	E2

* Refers to supporting policy number in Section 3.3; W = win; L = lose.

3.4 Adaptations for maintaining the contribution of fish to food security (F)

The projected decreases in coastal fisheries production caused by the direct and indirect effects of climate change {Chapter 9} are expected to widen the gap between the quantities of fish required for good nutrition, or eaten traditionally, and the fish available from coastal (and freshwater) habitats due to population growth in nine of the 22 PICTs {Chapter 12}. Decreases in coastal fisheries production are also expected to exacerbate problems in supplying fish for the large urban populations in another seven PICTs {Chapter 12}.

The adaptations and suggested policies for maintaining the important role of fish for food security in the region {Chapter 1} centre on minimising the size of this gap through (1) appropriate management of coastal (and freshwater) fish habitats and stocks; (2) increasing access to tuna for rural and urban populations; and (3) boosting pond aquaculture. The recommended adaptations are set out below. Many of these interventions are not new – they have been proposed for many years as an integral part of effective coastal zone management and ecosystem-based fisheries management, and to address the effects of population growth on the availability of fish for food security.

The community-based ecosystem approach to fisheries management (CEAFM) co-management framework, which integrates customary marine tenure and other social capital, local governance, traditional knowledge, self-interest and self-enforcement capacity, provides the most effective way to implement many of these adaptations. This is particularly the case when the adaptations are considered by cross-sectoral management advisory groups comprised of both government and non-government members.

3.4.1 Adaptations to safeguard fish habitats

➢ **Adaptation F1: Manage and restore vegetation in catchments (win-win)**

Sustaining coastal and freshwater fish production for food security in much of Melanesia begins with maintaining catchment vegetation {Chapter 12}. Good vegetation cover reduces the transfer of sediments and nutrients into river networks after heavy rainfall, and greatly reduces the potential impacts on freshwater and coastal fish habitats. Poor vegetation cover results in accelerated runoff and erosion {Chapter 7}, which directly damages coral reef, mangrove and seagrass habitats, and makes corals less resilient to bleaching {Chapters 5 and 6} (Figure 3.2). For freshwater habitats, lack of shade on riverbanks also increases exposure of fish to increasing temperatures. The main interventions needed to ensure that adequate levels of vegetation are maintained or restored in catchments are summarised below.

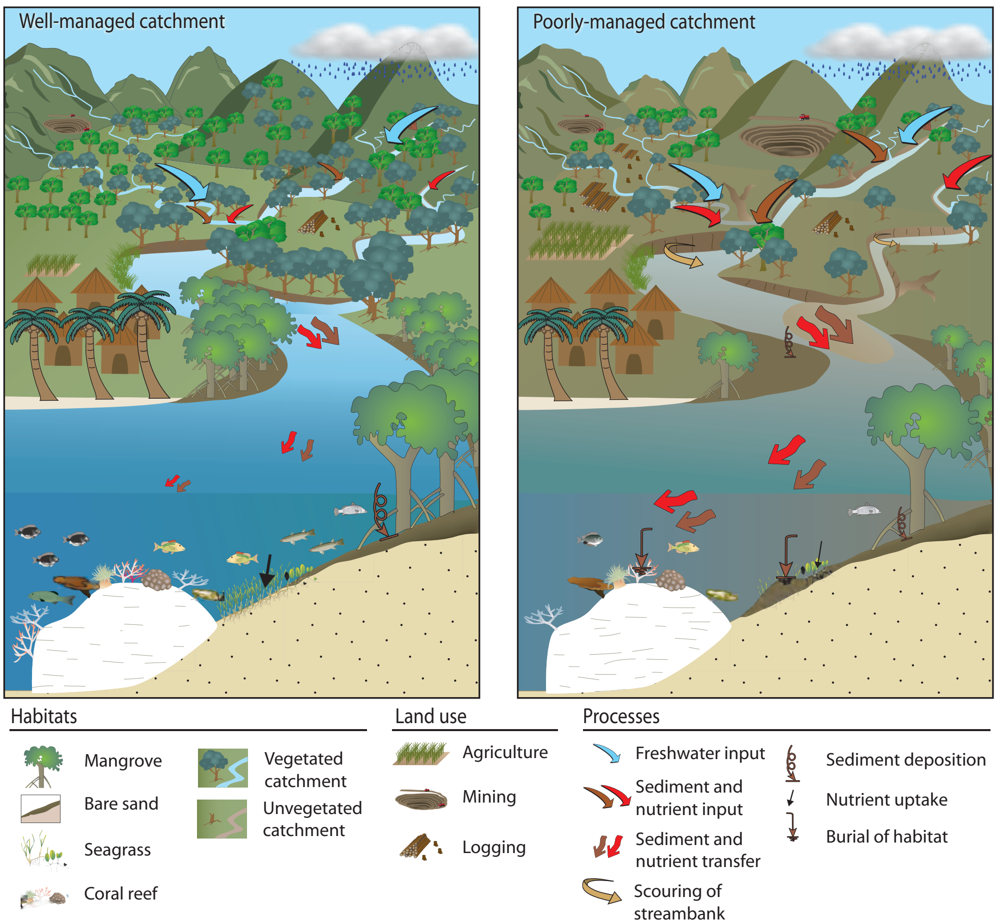


Figure 3.2 Differences in the quality of freshwater and coastal fish habitats under the influence of well-managed and poorly-managed catchments.

- Promote the importance of catchment management for fisheries at national planning meetings and obtain commitments from the agriculture, forestry and mining sectors to implement best practice to conserve vegetation and replant trees, minimise soil exposure and loss during construction of infrastructure, and prevent fertilizers and pollutants from entering watercourses.
- Encourage benign farming practices, including those built on traditional knowledge; raise awareness of the 'downstream' effects of poorly-designed agriculture and forestry operations (such as 'slash and burn'); and facilitate broad-based participation of customary owners, including men, women and youth, in the diversification of agro-forestry practices which are in harmony with the maintenance of fish habitats to build resilience to climate change.

Maintaining and restoring catchment vegetation should improve the quality of freshwater and coastal habitats in the short term. It should also help safeguard coastal habitats {Chapters 5 and 6}, and allow freshwater habitats to expand and support more fish {Chapters 7 and 10} in PICTs where rainfall is projected to increase {Chapter 2}.

➢ **Adaptation F2: Foster the care of coastal fish habitats (win-win)**

In addition to the vital importance of minimising sediment and nutrient inputs to the coastal zone from runoff, several measures are needed to improve the resilience of coastal fish habitats to climate change. These measures are listed below.

- Prevent deterioration in water quality that can arise from urban areas (e.g. sewage from humans and animal husbandry, chemical discharges, solid waste and factory effluent) by controlling pollution and managing waste. These are responsible interventions at any time, but require even greater attention in the future because the projected changes to coastal waters may reduce their capacity to attenuate waste.
- Eliminate activities that damage the three-dimensional structure of coral reefs, which provide much of the coastal fisheries production {Chapters 5 and 9}. Such activities include destructive fishing methods (particularly dynamite fishing), extraction of coral for building materials; careless anchoring of boats and tourism activities; and poorly-designed coastal infrastructure and tourist facilities. Degradation of coral reefs can also promote the incidence of ciguatera fish poisoning.
- Prohibit activities that reduce mangroves, e.g. removing trees, and damage the structural complexity of seagrasses, e.g. dredging or fishing with trawl nets {Chapter 6}.
- Raise awareness of communities about the dependence of fish and invertebrates on coastal habitats that may not already be part of their traditional knowledge (or has been lost). This involves liaising with communities to maintain connectivity

among coral reefs, mangroves, seagrasses and intertidal flats to (1) conserve the habitat mosaic needed for successful recruitment of juvenile fish and invertebrates, and (2) provide a diverse range of feeding areas for adult demersal fish {Chapters 6 and 9}.

- Enlist the assistance of NGOs, coral reef task forces[i], and programmes such as Seagrass-Watch[ii] to help communities protect fish habitats, while using these habitats for firewood, tapa, building materials and medicines etc., in ways that combine traditional approaches and government regulations for sustainable use of resources.

These measures should help maintain coastal fish habitats and recruitment of coastal fish and invertebrates in the short term. They are also expected to help make coral reefs, mangroves and seagrasses more resilient to the various stressors associated with climate change in the future, such as increased water temperature, greater turbidity and nutrient loads, acidification and sea-level rise {Chapters 5 and 6}.

➢ **Adaptation F3: Provide for landward migration of coastal fish habitats (lose-win)**

On large high islands, national planners and community leaders should avoid building infrastructure on low-lying land adjacent to mangroves, seagrasses and intertidal flats, which will eventually have to be protected from sea-level rise by erecting barriers to inundation. Instead, such low-lying areas should remain undeveloped to provide opportunities for fish habitats to migrate landward {Chapter 6}, particularly where projected increases in sea level {Chapter 3} are expected to inundate large areas of land. Because land is subject to traditional ownership in much of the region, national governments should help communities identify areas that will be inundated and consider compensating resource owners who agree to forego development of their land, if necessary.

Where existing road infrastructure blocks the inundation of low-lying land suitable for the colonisation of mangroves, channels and bridges should be constructed to allow inundation to occur. Communities should also be encouraged and trained to plant mangroves in such places to fast-track the establishment of the trees {Chapter 6}.

The short-term opportunity costs of this adaptation – loss of some uses of undeveloped low-lying land – are expected to be balanced by the benefits of maintaining fish habitats in the longer term. Some short-term benefits are also expected, however, through raising awareness among national planners of the importance of coastal fish habitats, and avoiding the construction of infrastructure on low-lying land that will be difficult to protect in the future.

i For example, the Coral Triangle Initiative (www.cti-secretariat.net/about-cti/plan-of-actions).

ii www.seagrasswatch.org/about.html

- **Adaptation F4: Allow for expansion of freshwater habitats (lose-win)**

The following management measures are needed to maintain, and maybe increase, freshwater fish production in the region under a changing climate.

- Allow river channels to migrate naturally so that there is no permanent loss of habitat quality and area following floods {Chapter 7}.
- Permit freshwater habitats to expand with increasing rainfall, by ensuring that inundation of undeveloped areas of floodplain habitats is not constrained {Chapter 7}.
- Remove or modify man-made barriers that prevent freshwater fish and invertebrates from retreating upstream as salt water penetrates further into rivers as sea level rises {Chapters 7 and 10}. Low-cost fishways constructed with local materials may improve access to upstream habitats in places where it is impractical to remove barriers such as causeways and weirs.

The opportunity cost for communities and governments associated with these adaptations is the alienation of land adjacent to rivers from some uses that may otherwise have been possible through engineering works to contain floods or prevent intrusion of salt water. However, the recommended measures should not only pave the way for expansion of freshwater and estuarine fish production under the projected increases in rainfall and sea-level rise {Chapters 2 and 3}, they should also prevent infrastructure from being built in places where it is likely to be at risk from climate change.

3.4.2 Adaptations to optimise catches from coastal demersal and freshwater fish stocks

- **Adaptation F5: Sustain production of coastal demersal fish and invertebrates (lose-win)**

Community-based ecosystem approaches to fisheries management should be strengthened in all PICTs without delay. Such CEAFM approaches should be based on primary fisheries management {Chapter 13} intended to keep production of demersal fish and invertebrates within sustainable bounds using a range of methods to assess data-poor fisheries. This precautionary approach will reduce the supply of demersal fish and invertebrates, but also reduce the gap between coastal fisheries production and the fish needed by rapidly growing populations by safeguarding the potential for stocks to be replenished. Conversely, poor management is likely to increase this gap {Chapter 12}. Understanding the dimensions of the gap will assist governments and communities to plan the adaptations needed to fill it (see below).

It is important to note, however, that CEAFM will need to be progressively more precautionary to allow for the increased uncertainty associated with climate change {Chapter 13}. Indeed, the effects of overfishing may become increasingly difficult to reverse because replenishment of local fish stocks from distant sources is expected to become more sporadic as increased sea surface temperature (SST) and altered ocean current patterns reduce the availability of juveniles from remote areas {Chapter 9}.

- **Adaptation F6: Diversify catches of coastal demersal fish (lose-win)**

Raising awareness among fishing communities of the alterations in species composition of demersal fish likely to be caused by a changing climate will assist communities to optimise catches. Changes in species composition are expected to be driven by (1) local increases in the abundance of some species not currently harvested due to changes in distribution; and (2) an increase in herbivorous species as a result of the expected changes in the structure of coastal habitats {Chapters 5, 6 and 9}. Diversifying fishing practices to take catches representative of the changes in relative abundance of species, within a primary fisheries management framework {Chapter 13}, should help maximise the potential to realise gains from the increases of some fish species.

Nevertheless, harvesting of herbivorous fish needs to be restrained to ensure they remain plentiful enough to remove the algae that inhibit the survival and growth of corals. An abundance of herbivorous fish is also expected to enhance the resilience of corals to increases in water temperature {Chapter 5}, with positive knock-on effects on other types of reef fish {Chapter 9}. Foregoing some of the catch of herbivorous species reduces potential supplies of fish in the short and long term, but should increase overall productivity of other demersal fish in the future.

- **Adaptation F7: Manage freshwater and estuarine fisheries to harness opportunities (lose-win)**

Community-based ecosystem approaches to fisheries management also needs to be introduced for PNG's extensive freshwater and estuarine fisheries, and smaller fisheries elsewhere in Melanesia. In contrast to coastal fisheries, the communities who depend on freshwater and estuarine resources can be guided to harvest more fish incrementally as production increases under greater projected rainfall and water temperatures, and sea-level rise {Chapters 7 and 10}. Effective primary fisheries management {Chapter 13} is needed to secure these benefits. Governments and communities can use the measures described below to take advantage of the projected increases in freshwater and estuarine fisheries production.

- Diversify fisheries over a wider range of species and habitats to harness the expected increases in freshwater and estuarine fisheries production, including fisheries based on species at low trophic levels (e.g. river herring), and introduced and invasive species tolerant of the direct and indirect effects of climate change (e.g. snakehead) {Chapter 10}. Fishing methods should also be developed for floodplain habitats presently considered inaccessible.

- Investigate ways to manage populations of low-value invasive species that may be favoured by climate change to reduce negative interactions with more valuable food species. For example, using walking catfish and climbing perch to produce fishmeal for pond aquaculture, or fish-silage fertiliser {Chapter 11}.
- Strengthen traditional mechanisms regulating access to, and use of, rivers and other freshwater habitats to conserve the projected increased benefits for rapidly growing resident communities.

Although CEAFM for freshwater and estuarine fisheries based on primary fisheries management limits production in the face of the great need for fish by the large inland communities in PNG, it should allow these fisheries to make greater contributions to food security as the projected increases in productivity occur due to climate change.

3.4.3 Adaptations to fill the gap in fish needed for food security

- **Adaptation F8: Increase access to tuna for urban and rural populations (win-win)**

The rich tuna resources of the region {Chapter 8} provide PICTs with the opportunity to fill the gap between the fish needed for good nutrition in urban and rural communities in the future, and the demersal fish expected to be available from coastal fisheries. The key adaptations for increasing access to tuna are described below.

- Promote the storage and distribution of low-value tuna and bycatch retained by industrial vessels to provide inexpensive fish for rapidly-growing urban populations. This adaptation should meet most of the shortfall in the fish needed for good nutrition in many of the main urban centres in the short and long term. It should be reinforced in PNG and Solomon Islands through increased landings of fish to supply the canneries being constructed there. In some other urban centres, e.g. Tarawa in Kiribati, projected changes in distribution of skipjack tuna should also make this adaptation easier to achieve {Chapter 8}. This adaptation should also aim to increase the involvement of women in the distribution and selling of low-value tuna and bycatch. In some of the smaller urban centres in the near term, care may be needed to release low-value tuna and bycatch onto the market in ways and at times that do not undermine the livelihoods of local small-scale commercial fishers.
- Transfer coastal fishing effort from demersal fish to nearshore pelagic fish, especially tuna. This can be done most effectively by installing networks of low-cost, fish aggregating devices (FADs) (Figure 3.3) anchored close enough to the coast (usually within 1–6 km from the shore at depths of 300–1000 m) to provide better access to skipjack and yellowfin tuna for subsistence and small-scale commercial fishers.

The technology for these anchored FADs has been developed over decades and works well, provided the FADs are placed where they attract mainly tuna and other oceanic fish, not pelagic fish closely associated with reefs {Chapter 9}. Anchored fish aggregating devices now cost ~ USD 1000–2000, depending on depth. The value of tuna and other fish caught around these FADs can greatly exceed the costs of construction and deployment. However, many communities will need training in the methods used to fish around FADs, and in post-harvest processing of catches (see below), to derive the full range of benefits. Networks of FADs should be seen as part of the national infrastructure for food security. Communities and their development partners should make plans to maintain FADs regularly, and replace them when they are lost.

a) b)

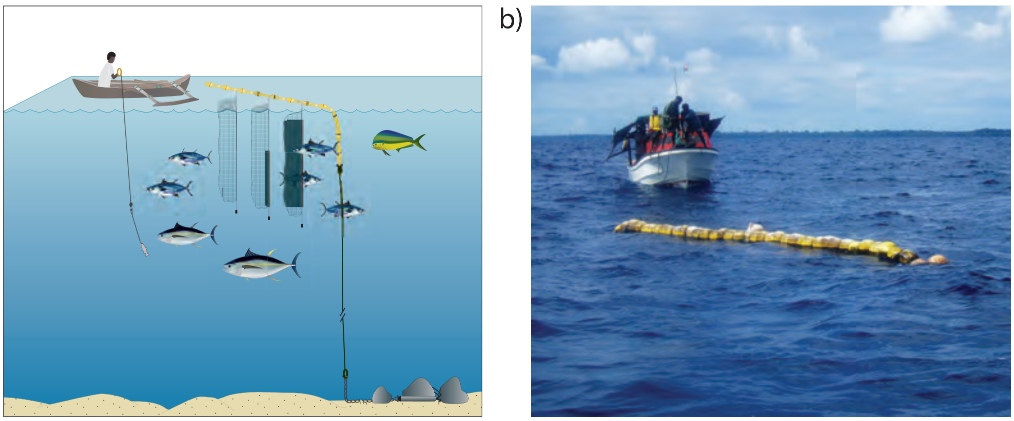


Figure 3.3 (a) Design of anchored, low-cost fish aggregating devices (FADs) suitable for placing in coastal waters (usually 300–1000 m deep) to increase access to skipjack and yellowfin tuna, and other large pelagic fish species; (b) surface buoys of a FAD in Papua New Guinea (photo: William Sokimi).

Transferring effort from demersal to nearshore pelagic fish should deliver much of the fish required for food by coastal communities {Chapter 12} in the short and long term. Increased reliance on nearshore pelagic fish should be favoured by climate change across the region until 2035, and in the east until 2100, due to projected changes in the distribution and abundance of tuna {Chapter 8}. Even in PNG and Solomon Islands, where tuna catches are eventually expected to diminish, tuna should still be plentiful enough to make anchored FADs an effective adaptation response to increasing human populations and declining demersal fisheries.

➢ **Adaptation F9: Develop pond aquaculture to diversify the supply of fish (win-win)**

Although there is great potential for tuna to supply PICTs with much of the additional fish they need for good nutrition of their populations {Chapter 12}, providing access to tuna everywhere in the region, or at all times, will not be possible. Development of pond aquaculture (Figure 3.4) in peri-urban areas, and for the benefit of inland communities in PNG and coastal communities with limited access to demersal fish or FADs in other PICTs, should also supply more fish {Chapters 11 and 12}. Pond aquaculture has long been successful in Asia, where much of the production is based on Nile tilapia *Oreochromis niloticus*, including genetically improved, farmed tilapia (GIFT) varieties. Nile tilapia are easy to reproduce and usually reach harvest size within 4–6 months in the tropics. Carp and milkfish also have potential for pond aquaculture {Chapter 11}.

Key considerations involved in implementing pond aquaculture are (1) selection of appropriate species; (2) design and construction of hatchery systems and networks that allow good quality fingerlings to be distributed effectively to farmers; (3) location of ponds where they will not be affected by floods; (4) availability of cost-effective feeds for semi-intensive and intensive farming systems, based on locally-available ingredients wherever possible; (5) capacity of fisheries staff and extension officers to provide training; (6) mechanisms for distributing production to markets; (7) possible effects on freshwater biodiversity of fish escaping from ponds; (8) prevention of effluent from intensive commercial operations in peri-urban areas from entering nearby rivers and coastal habitats; and (9) the threat of greater incidence of malaria as the breeding habitat for mosquitoes is increased through pond construction.

The simple, proven technology for farming species like tilapia, carp and milkfish is expected to help meet the growing demand for fish in some locations in the short term, and is likely to be favoured by the projected increases in rainfall and temperatures in the future {Chapter 11}. Availability of suitable feeds is likely to be one of the major limiting factors and could be exacerbated by increased exposure to shortfalls in global supplies of fishmeal due to climate change. Specific adaptations to secure adequate supplies of fishmeal include (1) rationalising allocation of fishmeal from tuna processing plants in the region for aquaculture and agriculture; (2) using undesirable introduced and invasive freshwater fish species in PNG to produce fish feeds at the village level; (3) replacing fishmeal with suitable local alternative sources of protein; and (4) promoting best management practice (BMP) for feeding of farmed fish to increase feed efficiency.

a) b)

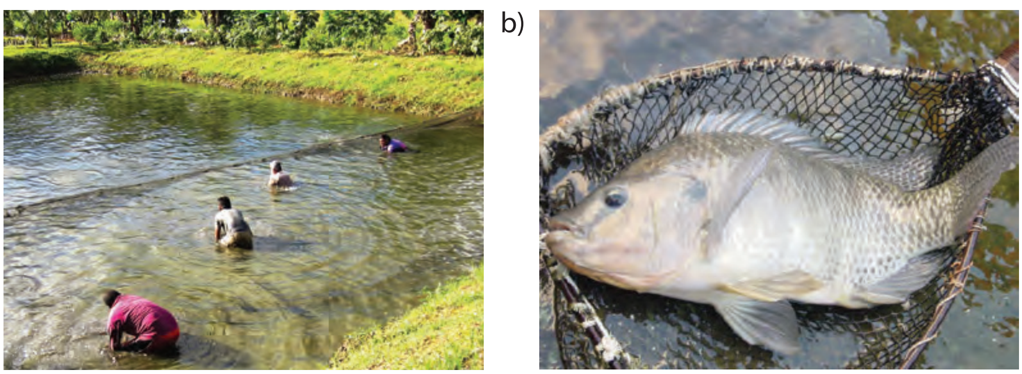


Figure 3.4 (a) Harvesting Nile tilapia from a freshwater pond in Fiji; and (b) a farmed Nile tilapia (photos: Timothy Pickering).

➢ **Adaptation F10: Develop coastal fisheries for small pelagic fish (win-win?)**

Diversify coastal fisheries to catch small pelagic species (mackerel, anchovies, pilchards, sardines, scads, fusiliers and squid), and support communities with the training and equipment required. The generally sustainable (though variable) nature of small pelagic fish harvests {Chapter 9} should provide access to more fish in the near term. The outlook for the long term is uncertain – projected decreases in primary productivity due to increased stratification associated with higher SST {Chapter 4} may cause abundance of small pelagic fish to decline. Conversely, projected increases of nutrients in coastal waters due to greater runoff may increase their production in some locations in the long term {Chapter 9}.

➢ **Adaptation F11: Improve post-harvest methods (win-win)**

Extend the shelf life of fish caught in coastal and inland areas by training communities, particularly women, in appropriate ways to improve traditional methods for smoke curing, salting and drying fish. In this way, coastal communities could make better use of large catches of tuna and small pelagic fish in the short term and, if climate change makes catches of these species more variable, in the long term. Improved post-harvest methods could also enable households to store fish for those times when conditions are not suitable for fishing and create opportunities to trade products with those inland communities without access to fish.

3.5 Supporting policies for maintaining the contribution of fish to food security (F)

The suggested policies required to implement the adaptations to maintain the contributions of fish to food security described in Section 3.4 are outlined below. Table 3.2 lists the policies that apply to each adaptation.

➢ **Policy F1: Strengthen governance and legislation to ensure the sustainable use and protection of all coastal and freshwater fish habitats** by (1) building the capacity of management agencies to understand the threats posed by climate change; (2) amending existing legislation to empower communities to manage fish habitats; (3) establishing networks to transfer this knowledge to rural communities; (4) introducing regulations and licence conditions for forestry and mining operations to reinforce protection for catchments and coastal fish habitats; (5) strengthening traditional and national institutions and regulations for sustainable use of coastal land and aquatic habitats; and (6) assisting communities to monitor changes in habitats and comply with management decisions and regulations.

➢ **Policy F2: Promote ecosystem-based management measures for agriculture, forestry and mining** at all levels to prevent damage to freshwater and coastal fish habitats through soil loss, transport of sediments and nutrients to watercourses and coasts, and pollution.

- **Policy F3: Protect source and resilient coral reefs** expected to supply recruits to 'downstream' reefs to help these reefs recover after coral bleaching or damage by cyclones.
- **Policy F4: Minimise barriers to landward migration of coastal habitats and expansion of freshwater fish habitats** during development of strategies to assist other sectors to respond to climate change.
- **Policy F5: Promote mangrove replanting programmes** in suitable areas {Chapter 6} to meet the twin objectives of enhancing habitat for coastal fisheries, and capturing carbon.
- **Policy F6: Apply primary fisheries management** to coastal and freshwater fish stocks to maintain their potential for replenishment.
- **Policy F7: Restrict export of demersal fish** to ensure that these resources are available for national food security where necessary (this policy does not apply to deepwater snappers).
- **Policy F8: Allocate tuna from national catches for food security**, so that rural and urban communities have greater access to fish.
- **Policy F9: Revise national and regional tuna management plans to provide the fish needed for local consumption**, including the general tuna management framework of the WCPFC.
- **Policy F10: Encourage coastal fishing communities to transfer effort to nearshore pelagic species** to supply more tuna for subsistence, and for local and urban markets.
- **Policy F11: Include FADs (anchored inshore) as part of the national infrastructure for food security**, ensure a maintenance programme is in place and make provision to replace FADs lost through wear and tear and storms.
- **Policy F12: Provide incentives for the private sector to purchase, store, process and distribute lower-value tuna** and bycatch landed by industrial fleets in major ports to increase access to fish in urban areas. Ensure that such enterprises comply with the Right to Food standards contained in the International Covenant on Economic, Social and Cultural Rights (ICESCR), and Humanitarian Law.
- **Policy F13: Dedicate a proportion of the revenue from fishing licences to improve management** of all fisheries and aquaculture, and access to fish for rural and urban populations. For example, by upgrading transport links to inland communities in PNG to enable better access to locally-canned tuna, and smoked and dried fish.
- **Policy F14: Provide incentives for the private sector** to invest in pond aquaculture, and support effective systems for producing and distributing fry to smallholders in rural areas.

- **Policy F15: Reconcile the use of introduced fish species for pond aquaculture with the potential effects on freshwater biodiversity** by zoning pond aquaculture. Until the research recommended (Sections 4 and 5) is completed, the introduction of Nile tilapia should be limited to (1) PICTs where coastal fisheries resources and local access to tuna are likely to be insufficient to meet the present and future recommended level of fish consumption for good nutrition {Chapter 12}; and (2) catchments where Mozambique tilapia *Oreochromis mossambicus* already occurs.
- **Policy F16: Strengthen national capacity, and collaboration between national agencies, to manage environmental issues** related to aquaculture development, such as application of Environmental Impact Assessment procedures that consider present and future risks associated with aquaculture proposals.
- **Policy 17: Provide training and technical support** for coastal fishing communities to catch small pelagic fish, and for inland and coastal communities to improve post-harvest methods to extend the shelf life of catches.
- **Policy F18: Revise primary school curricula to teach children about fish and food security**, focusing on (1) the importance of fish for their health; (2) the basic management actions needed to maintain fish habitats and fish stocks; and (3) the options for increasing future supplies of fish.

Table 3.2 Summary of adaptations and companion supporting policies to maintain the contributions of fish to food security for Pacific Island countries and territories (see Sections 3.4 and 3.5 for details).

Adaptation		Type	Supporting policy*
Adaptations to safeguard habitats producing fish			
F1	Manage and restore vegetation in catchments	W-W	F1, F2, F18
F2	Foster the care of coastal fish habitats	W-W	F1–F3, F18
F3	Provide for landward migration of coastal fish habitats	L-W	F4, F5, F18
F4	Allow for expansion of freshwater habitats	L-W	F4, F18
Adaptations to optimise catches from coastal demersal and freshwater fish stocks			
F5	Sustain production of coastal demersal fish and invertebrates	L-W	F6, F7, F13, F18
F6	Diversify catches of coastal demersal fish	L-W	F6, F13, F18
F7	Manage freshwater and estuarine fisheries to harness opportunities	L-W	
Adaptations to fill the gap in fish needed for food security			
F8	Increase access to tuna for urban and rural populations	W-W	F8–F13, F18
F9	Develop pond aquaculture to diversify the supply of fish	W-W	F13–F16, F18
F10	Develop coastal fisheries for small pelagic fish	W-W?	F13, F17, F18
F11	Improve post-harvest methods	W-W	F17, F18

* Refers to supporting policy number in Section 3.5; W = win; L = lose.

3.6 Adaptations for maximising sustainable livelihoods (L)

The eventual projected shift to the east in the distributions of tuna, decreases in production of coastal fisheries and coastal aquaculture commodities, and increases in production of freshwater fisheries and pond aquaculture, are expected to alter the availability of full-time jobs, and opportunities to earn income {Chapter 12}. Many of the adaptations and suggested policies required to minimise the loss of livelihoods derived from some fisheries and aquaculture activities, and to capitalise on the opportunities expected to be created for others, are the same as those described in Section 3.4. Examples include the imperative to conserve and restore fish habitats, the need to secure the supplies of tuna required to base more tuna processing operations within PICTs, switching fishing effort from demersal fish to nearshore pelagic fish, installing inshore FADs to improve access to tuna for small-scale commercial fishers, developing pond aquaculture in peri-urban areas, and marketing environmentally-friendly products. The additional adaptations needed to optimise the number of jobs that can be sustained by the sector are outlined below.

- **Adaptation L1: Improve technical and business skills of communities (win-win)**

Increase community participation in fishing around FADs and for small pelagic species, developing pond aquaculture and applying post-harvest methods. Together, these adaptations (Section 3.4) provide considerable opportunities to diversify income-earning activities. Training programmes to teach community members (including women) the necessary fishing and farming techniques, and small business skills, will be required to capitalise on these opportunities. Micro-finance schemes may also be needed to assist people to diversify into the broader range of fishing operations and value-added activities involved in these adaptations. Because the technology for all these adaptations already exists, these activities are expected to deliver benefits in the short term. The projected increases in abundance of tuna {Chapter 8}, and improvements in conditions for pond aquaculture {Chapter 11}, in many PICTs due to climate change means that investments in these adaptations are also likely to result in benefits well into the future.

- **Adaptation L2: Rebuild populations of sea cucumbers and trochus (lose-win)**

Primary fisheries management {Chapter 13} is needed to reverse the declines in stocks of sea cucumbers and trochus. For sea cucumbers, this involves (1) conservative harvests based on indicators such as species composition and size-frequency to restore the densities of adults to levels above the thresholds required for regular replenishment {Chapter 9}; and (2) strict controls on the size of individuals exported. For trochus, densities should be restored to 500–600 individuals per ha, with a wide spread of size classes. Harvests should then be restricted to 180 shells per ha per year, preferably with 3–5 year periods of moratorium between fishing events {Chapter 9}. This adaptation results in some loss of income while stocks are rebuilt, but sets the stage for greater benefits in the future. Although climate change may affect the productivity of sea cucumbers and trochus {Chapters 9 and 11}, more robust populations should have a greater resilience to increased water temperatures and ocean acidification.

- **Adaptation L3: Develop coral reef ecotourism ventures (win-win?)**

Reducing the pressure on fisheries resources by providing viable alternative sources of income for local communities in the tourism sector is expected to help maintain fish stocks within sustainable limits and make fisheries for demersal fish and invertebrates less vulnerable to climate change. However, the projected degradation of coral reefs due to increases in SST and ocean acidification may affect the long-term viability of ecotourism operations. Much care is also needed in the planning and construction of facilities for tourism to ensure that they do not affect the extent and quality of coastal fish habitats (Section 3.4).

- **Adaptation L4: Diversify production of coastal aquaculture commodities (win-win)**

Assess the potential to grow 'new' commodities in the region likely to (1) support profitable enterprises; and (2) be favoured by prevailing environmental, economic and social conditions in PICTs. Because the species involved in producing new commodities are most likely to be introduced from other regions, the potential risks to marine biodiversity need to be reconciled with opportunities to provide livelihoods. Otherwise, any production gains may be undermined by losses to other valued species.

- **Adaptation L5: Modify locations and infrastructure for coastal aquaculture (lose-win)**

A variety of adaptations can be made, as and when required, to reduce the expected negative effects of sea-level rise, ocean acidification and higher water temperatures on coastal aquaculture activities {Chapter 11}, as described below.

- Relocate pearl farming operations to sites close to existing coral reefs and seagrass meadows, where aragonite saturation levels are likely to remain high enough for good growth and survival of pearl oysters, and formation of high-quality nacre {Chapter 11}. This adaptation also applies to the small-scale village-based operations to culture giant clams and corals for the ornamental market.
- Raise the walls and floor of existing shrimp ponds so that they can continue to function under sea-level rise, and identify which ponds would need to be abandoned in favour of new structures further landward at higher elevations {Chapter 11}.
- Assess which alternative commodities (perhaps sea cucumbers) could be produced in ponds no longer suitable for shrimps in ways that do not impede landward migration of mangroves and seagrasses.

Such adaptations may involve foregoing production at existing sites or facilities, or production of present commodities, in an effort to ensure that aquaculture creates jobs in the future.

3.7 Supporting policies for maximising sustainable livelihoods (L)

The suggested policies needed to implement adaptations recommended for maximising the contributions of fisheries and aquaculture to livelihoods described in Section 3.6 are outlined below. The policies that apply to each adaptation are listed in Table 3.3.

- **Policy L1: Provide access to the training needed to operate profitable businesses** based on small-scale coastal fisheries and aquaculture activities for rural communities.
- **Policy L2: Develop partnerships with regional technical agencies** to provide the necessary technical support to manage coastal fisheries and develop aquaculture enterprises.
- **Policy L3: Promote private sector investment in coastal tourism designed to accommodate climate change**, particularly the projected changes in sea level, storm surge and changes to coral reefs and other coastal habitats.
- **Policy L4: Inform prospective private sector investors in coastal aquaculture** about the projected horizons for economically viable operations for each commodity under climate change.
- **Policy L5: Strengthen national and regional capacity to adopt and implement aquatic animal health and biosecurity measures,** including development of a regional aquatic biosecurity framework and international protocols for monitoring, detecting and reporting aquatic animal diseases to prevent introduction of new pathogens[51]. These measures will require cross-sectoral approaches, involving fisheries, quarantine and environmental agencies.
- **Policy L6: Provide incentives for aquaculture enterprises to assess risks to infrastructure** so that farming operations and facilities can be relocated if necessary.

Table 3.3 Summary of adaptations and companion supporting policies to maximise the contributions of fisheries and aquaculture to the creation of livelihoods in Pacific Island countries and territories (see Sections 3.6 and 3.7 for details).

Adaptation		Type	Supporting policy*
L1	Improve technical and business skills of communities	W-W	L1, L2
L2	Rebuild populations of sea cucumbers and trochus	L-W	L2
L3	Develop coral reef ecotourism ventures	W-W?	L3
L4	Diversify production of coastal aquaculture commodities	W-W	L4, L5
L5	Modify locations and infrastructure for coastal aquaculture	L-W	L6

* Refers to supporting policy number in Section 3.7; W = win; L = lose.

4. Gaps in knowledge

The vulnerability assessments summarised in Sections 2 and 6 were based on the best set of global climate models available when the assessment was prepared – the models used for the Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC-AR4) {Chapter 1}. However, much uncertainty still surrounds these assessments. This uncertainty is due to (1) the coarse grid sizes of these models and their inherent biases {Chapter 1}; and (2) gaps in the knowledge of the ecology of fish habitats and biology of harvested fish and shellfish.

The information needed to reduce uncertainty to progressively improve adaptations to climate change by the fisheries and aquaculture sector is outlined below.

4.1 Knowledge needed to improve the understanding of vulnerability

4.1.1 Surface climate and tropical Pacific Ocean

More long-term, high-quality data on surface weather are needed over a wider area of the region to (1) distinguish anthropogenic effects on surface climate from natural variability; (2) link local climate to larger-scale climate observations; and (3) validate and select the best-performing climate models for each region. Such data will also establish relationships between changes in rainfall and river flow on high islands.

Increased coverage and monitoring of ocean variables are also required. In particular, the vertical distribution of nutrients, oxygen and pH needs to be measured regularly over a much more representative area of the tropical Pacific Ocean to parameterise and validate models simulating the responses of the ocean to different emissions scenarios.

To improve the next generation of global climate models, significant biases in the CMIP3 models need to be addressed. These major biases include (1) the overly zonal orientation of the South Pacific Convergence Zone, which limits confidence in projections of the rainfall and wind fields of the central-southern Pacific; and (2) the warming associated with ENSO events, which is generally situated too far to the west and often occurs too frequently. A better understanding of the physical mechanisms driving these characteristics is needed to improve the parameterisation of coupled atmosphere-ocean models.

The resolution of global climate models also needs to be increased so that they 'see' PICTs. Dynamical and statistical techniques to downscale global climate models are available and under continuous development to enable projections to be made for smaller areas. However, considerable further effort is needed to determine how best to implement downscaling approaches to provide robust projections of changes to surface climate and the ocean at scales meaningful to management in PICTs. This work is now underway through Australia's Pacific Climate Change Science Programme[i].

4.1.2 Fish habitats

Open-ocean food webs

The extent to which climate change is likely to alter the availability of nutrients and oxygen that underpin food webs for tuna in the tropical Pacific Ocean, and the populations of phytoplankton, zooplankton and micronekton that comprise these food webs, is still poorly understood. Few reliable biogeochemical models can be linked to global climate models to project changes to these food webs and, apart from the Hawaii Ocean Time-Series station in the North Pacific Tropical Gyre {Chapter 4}, no long-term observations of nutrient and oxygen levels or the abundances of phytoplankton, zooplankton and micronekton exist in the region. More long-term time-series data are a priority. Better biogeochemical models will also pave the way for improved application of ecosystem models of upper trophic levels (e.g. SEAPODYM – Spatial Ecosystem and Population Dynamics Model, and Ecopath) to project the effects of changes in components of the food web on local abundances of tuna.

The research activities required to parameterise the biogeochemical models needed to improve our confidence in simulations of tuna catches under a changing climate are outlined below.

- Assess the effects of higher atmospheric concentrations of CO_2 on the carbon-to-nitrogen ratio of organic matter in the ocean through networks of *in situ* observations and laboratory experiments.
- Identify the spatial and temporal distribution of iron in the Equatorial Undercurrent, and the future bio-availability of different forms of iron, to determine whether the present limitations on production of phytoplankton in the nutrient-rich Pacific Equatorial Divergence Province (PEQD) {Chapter 4} are likely to continue.
- Describe the variability in abundance of micronekton, and factors driving this variability. This involves validating the acoustic methods used to assess micronekton by correlating the data with micronekton sampled using nets, and from the stomach contents of tuna and other top predators.

i www.cawcr.gov.au/projects/PCCSP

- Evaluate the extent of lateral transport of organisms from nutrient-rich oceanic provinces such as PEQD to nutrient-poor provinces, particularly within the aphotic zone.

Coral reefs

To reduce the uncertainty about how emissions of CO_2 and other greenhouse gases are likely to affect coral reefs {Chapter 5}, the following questions need to be answered.

- How are warming and acidification of the tropical Pacific Ocean affecting the early life history stages of corals and other key reef-building organisms? What are the knock-on effects of these processes on the wide range of species that comprise the food webs of the fish and invertebrates harvested from coral reefs?
- What is the effect of ocean acidification and warming on the relative balance between calcification and erosion? How would changes in this balance affect reef structure?
- Will synergies between projected increases in ocean acidity, SST and nutrient loads, and possibly more powerful waves from stronger tropical cyclones, damage coral reefs more severely?
- Which management strategies are likely to be most effective for coral reefs that have been bleached? Should closures to fishing and tourism be put in place until reefs have recovered?
- What are the likely consequences for coral reefs of a very rapid rise in sea level {Chapter 3}?
- Which coral reef habitats are likely to have the greatest natural resilience to bleaching, ocean acidification and other impacts of climate change?

Mangroves, seagrasses and intertidal flats

There are still major gaps in our knowledge of the distribution, diversity and coverage of mangrove and seagrass habitats, and the areas of intertidal flats, across the tropical Pacific {Chapter 6}. In many cases, even the existing estimates of habitat area are likely to be gross underestimates. In addition to providing estimates of habitat area for several PICTs, and checking the accuracy of estimates already made for PICTs, the following information is needed to improve our understanding of the vulnerability of these habitats and the roles they play in supporting coastal fisheries.

- Sensitivity of mangroves and seagrasses to sea-level rise and rates of sedimentation. Mapping deep meadows will help identify the seagrass habitats most at risk.
- The locations where mangrove and seagrass habitats are likely to have greater natural resilience to thermal stress, ocean acidification and the other projected impacts of climate change.

- The contributions of epifauna and infauna to the food webs of demersal fish and invertebrates associated with mangroves, seagrasses and intertidal flats, and the vulnerability of these food webs to the projected effects of climate change on these habitats {Chapter 6}.

Freshwater rivers and estuaries

Of all the fish habitats in the region, the least is known about freshwater rivers and estuaries {Chapter 7}. Ecosystem models for representative river types need to be developed and validated so that managers do not have to rely on information from other parts of the world. Important first steps are to quantify and map the habitats created by rivers and estuaries, and to set benchmarks for identifying changes in habitat area and quality. This basic research will also identify places where there is strong connectivity between habitats during the life cycles of migratory fish and invertebrate species {Chapter 10}. Information on the diversity, extent, function and connectivity of freshwater and estuarine habitats will help adjacent fishing communities to understand the contributions of these ecosystems to their food security and livelihoods.

4.1.3 Fish stocks

Oceanic fisheries

In addition to the need to downscale global climate models (Section 4.1.1), and parameterise biogeochemical models with better information on nutrients, iron and micronekton (Section 4.1.2), more knowledge about the biology of tuna is required to improve confidence in projected future catches simulated by the SEAPODYM model {Chapter 8}. The main gaps in knowledge to be filled are listed below.

- Identify the likely responses of skipjack, yellowfin, bigeye and albacore tuna to variation in key environmental variables, including:
  - optimal temperature and dissolved oxygen ranges and thresholds for different life history stages;
  - potential effects of increased ocean acidification on production of gametes, fertilisation, embryonic development, hatching, larval behaviour and feeding ecology (restricted to yellowfin tuna in the first instance because this is the only species of tropical tuna propagated in captivity);
  - interactions among the effects due to temperature and ocean acidification; and
  - possible changes in vertical distribution of each species of tuna due to variation in temperature and dissolved oxygen, and the consequences for their vulnerability to capture by different gear types.
- Assess the carrying capacity of the pelagic ecosystem for tuna in the tropical Pacific, and whether the productivity of stocks is controlled directly by food

abundance, or by non-linear relationships such as variation in food assimilation rates with changes in prey density. These tasks require a good understanding of:

- energy transfer efficiency between all levels of the food web, but especially from the lower levels to the mid-trophic level (micronekton);
- spatial and temporal variation in diversity, distribution and abundance of micronekton across the region;
- diets of the four species of tuna, and the scope for competition between the species; and
- nutrient-rich coastal waters as feeding areas for tuna, and the possible retention of tuna in such areas – the archipelagic waters under the influence of increased runoff from the Sepik-Ramu river system in PNG are of particular interest {Chapter 8}.

Coastal fisheries

A better understanding of the likely effects of climate change on the production of coastal fisheries depends on identifying the responses of key fish and invertebrate species to projected alterations in environmental conditions and habitats. The main research activities involved are listed below.

- ➢ Assess the role of coral reefs, and variation in their structural complexity and biological diversity, in determining the distribution and abundance of associated fish and invertebrate species, especially during larval settlement and recruitment. This research is closely linked to assessing the comparative resilience of different reef-building corals (Section 4.1.2).
- ➢ Investigate the role of mangroves, seagrasses and intertidal flats in supporting demersal fish and invertebrates, particularly their importance as nursery and feeding areas, and their links with coral reefs. We also need to know whether fish and invertebrates use these habitats sequentially as they grow, and whether the juxtaposition of habitats within the mosaics they form affects fisheries production.
- ➢ Assess the sensitivity and adaptive capacity of key demersal fish species and invertebrates to changes in SST and pH, including (1) the effects on early life history stages; and (2) the combined effects of these variables and their interactions with other anthropogenic stressors.
- ➢ Model the effects on larval dispersal of decreases in the strength of the South Equatorial Current and the South Equatorial Counter Current {Chapter 3}.
- ➢ Determine whether a link exists between the risk of ciguatera fish poisoning and climate change. In particular, whether populations of the toxic microalgae *Gambierdiscus* spp. are affected by the deterioration of coral reefs, and whether the projected changes in SST are likely to alter the distribution, occurrence and virulence of ciguatera.

- Estimate the risks of any alteration in the incidence of other harmful marine algae caused by climate change to coastal fisheries and communities that rely on coastal fish for food.
- Evaluate the likely effects of higher levels of nutrients from the projected increases in runoff around high islands in tropical Melanesia on the productivity of small pelagic fish species.
- Assess the vulnerability to climate change of deepwater demersal species taken by coastal fisheries, especially snappers and groupers.

Freshwater and estuarine fisheries

To increase confidence in the vulnerability of these poorly understood fisheries, basic research is needed on the biology of the main species, particularly the way they use various habitats at different stages of their life cycles, and their responses to changes in habitat availability and quality. It is also important to understand interactions among fish species (including introduced and invasive species) and to determine whether such interactions are likely to be affected by the projected changes to water temperature and flow rates {Chapter 10}. Research on fish and invertebrates that are exposed to a wider range of climate change effects because they migrate between freshwater and the sea is a priority.

4.1.4 Aquaculture

Pond aquaculture

In addition to any modifications needed to adapt the well-established methods for pond aquaculture for the region {Chapter 11}, other research activities are required to (1) assist PICTs to evaluate whether pond aquaculture is likely to be enhanced as a result of climate change; and (2) identify any possible disadvantages of pond aquaculture as a way of increasing access to fish. These research activities are outlined below.

- Couple global climate models to the level of river catchments so that planners, managers and stakeholders can combine this information with geographic information system (GIS) data to identify areas most likely to be suitable for pond aquaculture in the future.
- Evaluate any potential impacts of Nile tilapia introduced for pond aquaculture on freshwater biodiversity. This research needs to be designed to ensure that any effects of escaped fish on biodiversity are not confounded with alterations to freshwater habitats caused by poor management of catchments {Chapter 7}. Because Mozambique tilapia are well established throughout the region, it will also be important to determine whether Nile tilapia that escape from ponds are likely to have any impact on biodiversity over and above any effects attributed to Mozambique tilapia.

- Identify the likelihood that warmer and wetter conditions may increase the risks posed to pond aquaculture by disease {Chapter 11}.
- Assess whether freshwater aquaculture ponds increase habitat for malaria mosquitoes (*Anopheles* spp.) and, if so, identify how ponds could be managed to reduce the risk.

Commodities for livelihoods

Research is needed to determine whether coastal habitats in the tropical Pacific will continue to be suitable for the production of aquaculture commodities for livelihoods in the face of climate change. The main research tasks are summarised below.

- Assess whether the temperature fluctuations during the short 'spring' and 'autumn' seasons in New Caledonia that cause mortality of shrimp are likely to be reduced or accentuated in the future.
- Evaluate the scope for extending seaweed farming to Vanuatu as temperatures warm. If it is considered technically feasible, gender-based, socio-economic research will be needed to determine whether the relatively low incomes involved are likely to (1) meet the expectations of coastal communities; and (2) result in sufficient production to warrant establishment of enterprises to export the products.
- Determine the likely effects of ocean acidification on (1) survival of pearl oysters and formation of high-quality pearls; (2) recruitment of milkfish postlarvae used to stock ponds; and (3) fitness of sea cucumbers released in sea ranching projects, due to effects on the size and strength of spicules. If acidification has significant effects on pearl quality, research will be needed to identify whether microsites exist where the buffering effects of nearby coral reefs, macroalgae and seagrasses {Chapters 5 and 6} maintain aragonite saturation levels within the limits required by pearl oysters to produce high-quality nacre.
- Ascertain whether pathogens affecting the pearl and shrimp industries are likely to become more virulent with increasing water temperatures.

4.2 Knowledge needed to implement adaptations effectively

4.2.1 Economic analysis

The rich tuna resources of the region provide PICTs with many potential adaptations to maintain the benefits of fisheries for food security and livelihoods (Section 3.4), even under the projected redistribution of tuna to the east {Chapter 12}. It is already evident that 'domesticating' the tuna industry to create jobs on fishing vessels and in processing operations adds much value to local economies compared with selling access rights to DWFNs {Chapter 12}. However, economic analysis is needed to determine the relative benefits of allocating a proportion of estimated sustainable tuna catch to subsistence and small-scale commercial fishers, compared with allocating it all to DWFNs or domesticating the industry. In particular, governments need to know how the social (health) and economic benefits people receive from catching and eating fresh tuna, or selling it at a local market, compare with the benefits people receive via national revenue from licence fees, or from jobs in the tuna industry.

Provided such analyses encompasses the effects of population growth on local demand for fish, and the effects of climate change on the projected availability of tuna, they should (1) aid PICTs to optimise future benefits from their tuna resources, and (2) identify the best ways to provide access to the fish (or other animal protein) needed for food security {Chapter 12}. The results are expected to differ among PICTs, depending on the estimated sustainable catches of tuna from their EEZs, the size of their populations, their capacity to domesticate fishing and processing operations, and the availability of other opportunities for people to earn income.

4.2.2 Social dimensions

Considerable gaps in knowledge still exist about how Pacific communities are likely to embrace the recommended adaptations and the need for change. Learning to catch or produce fish in new ways, and to eat different types of fish, are important adjustments for communities to make in preparation for the times ahead. Research is needed to gauge the willingness of people to make these changes, and how to assist them where necessary. The traditional social mechanisms used by Pacific people to respond to extreme events, such as tropical cyclones and droughts (Section 13.4), should predispose them to make a smooth transition to the recommended adaptations. But such responses should not be assumed. The suitability of these traditions for the projected changes in the production of fisheries and aquaculture under the A2 emissions scenario needs to be examined.

5. Investments required

To maintain the important contributions of fisheries and aquaculture to economic development, government revenue, food security and livelihoods, PICTs and their development partners will need to make investments at several levels. In particular, investments are needed to:

1. launch the win-win and lose-win adaptations to address the threats and opportunities associated with climate change and other drivers (Section 3);
2. fill the gaps in knowledge required to improve our understanding of vulnerability (Section 4);
3. strengthen the partnerships needed to implement adaptations effectively and fill the gaps in knowledge; and
4. monitor the projected effects of climate change on fisheries and aquaculture, and the success of adaptations {Chapter 13, Section 13.7}.

5.1 Investments to implement adaptations

The adaptations recommended in Section 3 to reduce the threats posed by climate change to contributions by fisheries and aquaculture to Pacific communities, and to capitalise on the opportunities, will require the following investments.

5.1.1 Economic development and government revenue

- Full implementation of the vessel day scheme for the purse-seine and the longline fisheries by all PNA members, together with similar management arrangements to limit fishing effort for tuna in subtropical waters by the members of the Te Vaka Moana Arrangement.
- Development of a long-term economic partnership agreement (EPA) with the EU by PNG, Fiji and Solomon Islands to help secure future supplies of tuna for their canneries.
- Establishment of (1) competent authorities for fishery product food safety and the associated testing laboratories or services, and (2) systems for demonstrating compliance with IUU fishing regulations in PICTs well placed to supply canneries in those countries which have EPAs with the EU.
- Energy audits and energy efficiency programmes for national industrial tuna fleets to assist them to cope with fluctuations in oil prices, and reduce the costs of fishing further afield as the distribution of tuna shifts to the east.
- Safety audits for purse-seine and longline vessels.

- Production chain accounting of all emissions from tuna fishing and canning/processing operations, and transport to markets, for carbon labelling of tuna products from the region.
- Training of women for managerial roles in tuna canneries and loining plants.

5.1.2 Food security and livelihoods

- Integrated land use planning to stabilise soils and prevent high sediment loads from entering streams and reaching the coast, including (1) revegetation of areas in catchments most likely to intercept sediment, and (2) establishing well-vegetated riparian (stream side) buffer zones. Revegetation will not only reduce the vulnerability of fish habitats {Chapters 5–7}, it will help mitigate CO_2 emissions by boosting carbon sequestration. Pacific leaders identified solutions to deforestation and forest degradation as a key response to climate change in their 'Call to Action on Climate Change' in 2009[ii].
- Cross-sectoral cooperation in the development of national adaptation programmes of action (NAPAs) to (1) integrate the protection and management of coral reef, mangrove, seagrass and intertidal flat fish habitats, and freshwater and estuarine fish habitats, with other plans to assist all sectors adapt to climate change; and (2) identify the modifications to infrastructure needed to allow mangroves and other coastal fish habitats to migrate landward as sea level rises.
- Capacity-building of fisheries agencies and management advisory groups in all PICTs to guide communities in (1) implementing CEAFM, incorporating primary fisheries management and ecosystem-based approaches to management of coastal and freshwater fish habitats and stocks {Chapter 13}, and (2) assessing the implications of climate change and the cost and effectiveness of potential adaptation options.
- Practical business models, and incentives, for the private sector to engage in storage, processing and distribution of low-cost tuna and bycatch landed at major ports, to provide increased access to fish for rapidly growing urban populations.
- Cost:benefit analysis of producing canned tuna for local and export markets.
- Assessment of the feasibility and practicality of using a portion of licence fees from DWFNs to offset the cost of locally-canned tuna for inland populations in PNG.
- Surveys to identify the best sites for installing inshore FADs to increase access to tuna for subsistence and small-scale commercial fishers in rural areas, followed by programmes to install and maintain FADs at these sites as part of the national infrastructure for food security. This will involve maintaining stockpiles of equipment at national fisheries agencies to replace FADs as required.

ii Pacific Islands Forum Secretariat, Forum Communiques; www.forumsec.org.fj/pages.cfm/documents/forum-communiques

- Analysis to identify the prime locations for peri-urban and rural pond aquaculture based on information on rainfall and temperature from downscaled global climate models, and other demographic and natural resources layers available for GIS.
- National and private-sector hatcheries to produce juvenile fish for pond aquaculture, supported by distribution networks to deliver high-quality juveniles to rural areas.
- Evaluation of the potential merits of micro-credit schemes and training programmes to enable coastal communities to (1) develop small-scale commercial fisheries around FADs and for small pelagic fish species; (2) expand pond aquaculture; and (3) scale-up post-harvest processing, where credit is recognised as a barrier to implementing these adaptations.
- Training and capacity building for coastal communities, especially women, to engage in (1) income-earning opportunities created by diversifying food production systems (in fisheries, aquaculture and agriculture) to build resilience to climate change; and (2) operate small businesses.
- Analysis of carbon footprints of the main aquaculture operations, and identification of better ways to conserve energy along the supply chain. Such investments should also consider innovative strategies to market environmentally-friendly products based on better management of natural resources.

5.1.3 Increasing participation and awareness

- Research to identify the key social mechanisms and drivers that influence participation by men, women and youth in the planning, design and implementation of adaptations to climate change.
- Educational materials to assist communities to understand (1) the contributions of fisheries and aquaculture to food security and livelihoods; (2) the fundamentals of climate change; (3) the timing of the projected effects of climate change on fisheries and aquaculture, and (4) the need to manage catchments and freshwater and coastal fish habitats well to improve the resilience of fish stocks to climate change.
- Interactive and educational computer games for children to (1) promote learning (by having fun) about vulnerability of fisheries and aquaculture (and other sectors) to climate change; (2) help them understand the consequences of adapting or not adapting; and (3) allow them to recognise other disaster risk management choices and outcomes.

5.2 Investments to fill gaps in knowledge

The information set out in Chapters 2–12 describes our current understanding of the natural and social processes underpinning the contributions of fisheries and aquaculture to the well-being of Pacific communities, and how these processes are likely to be affected by climate change. This knowledge is far from complete. The investments needed to improve and regularly update this vulnerability assessment are summarised below.

5.2.1 Surface climate and the tropical Pacific Ocean

- Building the capacity of PICTs to (1) forecast the weather and make short-term seasonal climate predictions, particularly for tropical cyclones and ENSO events; and (2) operate appropriate warning systems for severe weather events and other potential natural catastrophes (earthquakes and tsunamis).
- Constructing additional weather stations throughout the region to make long-term, high-quality surface weather observations, to assist PICTs to (1) detect the nature and significance of changing climates; (2) link relevant island-scale weather patterns to larger-scale climate observations; and (3) relate changes in rainfall to variations in local river flows and groundwater regimes.
- Developing higher-resolution physical global climate models that (1) address existing biases in the position of the South Pacific Convergence Zone and the spatial and temporal structure of ENSO, and (2) are capable of projecting changes to the frequency and intensity of ENSO events and tropical cyclones. These downscaled models are needed to provide a better understanding of the likely changes to the surface area and structure of the Warm Pool and PEQD, which are of great significance to the distribution and abundance of tuna.

5.2.2 Oceanic fisheries

- Expansion of the SEAPODYM model used to estimate tuna catches under different climate change scenarios to (1) link higher-resolution, physical global climate models to better biogeochemical models (see below); and (2) incorporate socio-economic scenarios likely to drive future fishing effort in the region (e.g. increasing demand for tuna from industry and from PICTs for food security, demographic changes, projected spatial changes in fishing effort, and increasing fuel costs).
- Development, parameterisation and verification of biogeochemical models, including collection of data on variability of nutrients, oxygen, pH, phytoplankton, zooplankton and micronekton throughout the water column; movements of tuna; diets of juvenile and adult tuna; and the responses of juvenile tuna to ocean acidification. This involves:
  - obtaining catch data from vessel logbooks reporting the exact locations where fish were caught in the tropical Pacific Ocean;
  - establishing long-term monitoring stations for physical and chemical variables in all provinces;

- adding biochemical and acoustic sensors to the Tropical Atmosphere Ocean (TAO) array of moorings in the Warm Pool and PEQD, and/or to the Argo floats[iii];
- continuing the satellite remote sensing of SST and chlorophyll *a*, so that changes in the convergence zone between the Warm Pool and PEQD can be tracked easily;
- validating the accuracy of acoustic data in discerning the relative abundance of the main groups of micronekton, so that 'ships of opportunity' fitted with suitable instrumentation can build up time-series of variation in micronekton along major shipping routes[iv];
- supporting observers on industrial tuna vessels to sample micronekton from the stomachs of tuna and other top predators;
- tagging programmes for all four species of tuna, both with conventional and electronic tags, to verify projected changes in their distributions in response to altered nutrients, water temperatures, currents and oxygen levels, including movements in archipelagic waters; and
- assessing the effects of ocean acidification on recruitment success of tuna larvae.

➢ Regular assessments of the projected catches of all four species of tuna under selected climate change scenarios every 5–7 years, using the enhanced SEAPODYM model {Chapter 8}, to inform regional and national management agencies.

5.2.3 Coastal fisheries

➢ Sampling programmes to determine how (1) spatial and temporal variation in environmental stressors, such as SST, affect the three-dimensional architecture of the coral reefs that support demersal fish {Chapter 9}, and (2) coral reefs respond to appropriate management measures to prevent degradation.

➢ Modification of the available satellite products to (1) provide the finer-scale measurements (< 1 km grid size) needed to manage individual reefs; and (2) integrate data on light intensity, pH and turbidity with SST.

➢ Maps of mangroves, seagrasses and intertidal flats for all PICTs to help (1) quantify the contribution of these habitats to coastal fisheries production; (2) raise awareness among coastal planners of their importance; and (3) provide a baseline for monitoring changes in the area, density and species composition of mangroves and seagrasses, and the area of intertidal flats.

iii www.argo.ucsd.edu

iv See www.imber.info/CLIOTOP_MAAS.html for more details.

- Continued collection of reliable data on sea-level rise in PICTs through the South Pacific Sea Level and Climate Change Monitoring Project.
- Higher-resolution topographic maps to identify more accurately (1) the projected losses of mangroves and intertidal flats blocked from migrating landward by infrastructure; and (2) the areas likely to be inundated that have potential for colonisation by mangroves and seagrasses.
- Surveys of the biodiversity, relative abundance and size composition of fauna associated with coral reefs, mangroves, seagrasses and intertidal flats at representative locations to improve our understanding of the food webs for coastal fisheries supported by these habitats.
- Research on key fish and invertebrate species harvested by coastal fisheries to determine:
    - how their distributions and abundances are linked to the coral reef, mangrove, seagrass and intertidal flat habitats that support them, and how these relationships are likely to change as these habitats are degraded {Chapters 5 and 6};
    - the likely effects of increases in SST and ocean acidification, and changes in the strength of major ocean currents, on successful recruitment of fish to coastal habitats;
    - whether the incidence and virulence of ciguatera fish poisoning is likely to vary as SST increases, and as coral cover decreases and macroalgae increase; and
    - the possible effects of increased runoff from high islands on the abundance of small pelagic fish species.

5.2.4 Freshwater and estuarine fisheries

- Higher-resolution elevation maps and flood modelling to identify likely changes to floodplain and estuarine fish habitats. This information will allow national planners to provide for increased fisheries production when developing cross-sectoral strategies to adapt to projected increases in rainfall and sea-level rise.
- Development of fisheries production models for the Fly and Sepik-Ramu rivers in PNG, based on (1) inventories of freshwater habitats and elevation mapping; (2) better data for catch and fishing effort, especially for subsistence fisheries; and (3) improved projections of flow rates, nutrient loads, water temperature and dissolved oxygen from downscaled global climate models.

5.2.5 Aquaculture

- Impact risk assessments for the introduction or further translocation of Nile tilapia for pond aquaculture. These assessments should provide decision-makers with science-based advice about any possible effects on freshwater biodiversity, ensuring that any such potential effects are not confounded with habitat degradation, and are relative to any existing impacts on biodiversity that can be attributed unequivocally to Mozambique tilapia.

- Assessments of how long existing shrimp ponds are likely to function efficiently, followed by modifications to, or relocation of, ponds when required to ensure that they can be dried completely between crops as sea level rises {Chapter 11}.
- Research to determine the likely effects of ocean acidification on growth and survival of juvenile and adult pearl oysters, and pearl quality. In the event of projected deleterious effects, investments should be made to identify micro-sites that may retain adequate aragonite saturation levels due to buffering by nearby reefs and seagrasses to support continued farming of pearls and other commodities likely to be affected by ocean acidification (e.g. corals and giant clams for the ornamental trade).

5.3 Investments to strengthen partnerships

Because many PICTs have limited national technical capacity, investments are needed to develop the technical and scientific teams required to assist PICTs to (1) implement and refine the key adaptations described in Section 3; (2) improve their understanding of the vulnerability of fish habitats, fish stocks, and the enterprises and communities depending on these resources; and (3) fill the remaining gaps in knowledge.

In the case of coastal fisheries, this will involve providing continued support to the scientific institutions, regional organisations and non-governmental organisations (NGOs) already assisting PICTs to implement CEAFM. For oceanic fisheries, partnerships are needed to provide research teams with better access to Pacific basin-wide fishing data sets, i.e. combined databases from WCPFC and IATTC, as the distributions of skipjack, yellowfin and bigeye tuna move progressively east.

Support for the continued development of the Global Partnership for Climate, Fisheries and Aquaculture (PaCFA)[v] should also be considered to ensure that lessons learned from other regions can be passed on to PICTs, and vice versa.

5.4 Investments to monitor changes in resources and the success of adaptations

Investments in a variety of monitoring programmes are required to assist PICTs to improve their understanding of the status of natural resources, assess whether the projected effects of climate change on these resources are occurring, and measure the success of adaptations. The specific investments needed are outlined below.

v www.climatefish.org

- Development of a digital image analysis system to record changes in species composition and size-frequency of tuna caught by purse-seine vessels, where data can preferably be processed by computers on board and transmitted to the Forum Fisheries Agency and Secretariat of the Pacific Community via the vessel monitoring system.
- Regular mapping of vegetation cover in catchments to monitor the success of revegetation programmes.
- Long-term monitoring programmes to (1) inform PICTs about changes in coastal fish habitats and stocks of demersal fish (including market sampling); (2) determine the variation in habitats and stocks due to climate change, as opposed to other drivers; and (3) assess whether the effects of climate change are occurring as projected.
- Modifications to household income and expenditures surveys and censuses to measure the success of adaptations (against socio-economic baselines) in maintaining the contributions of fisheries and aquaculture to food security and livelihoods.

5.5 Investments to localise the vulnerability assessment

The results of this assessment need to be transferred to the local level by supporting NGOs and other agencies to assist communities to make semi-quantitative evaluations of their vulnerability {Chapters 2–12}. Such semi-quantitative evaluations involve applying regional and local knowledge at a community level to identify and understand the specific sources of vulnerability, and how these can be minimised. This approach allows integration across sectors and scales to produce effective adaptation plans. It also builds capacity within communities to implement adaptations.

6. Technical summaries

6.1 General approach and use of climate models

General approach

The assessments of the vulnerability of fisheries and aquaculture in Pacific Island countries and territories summarised in this volume were based on the best science available at the time. Published scientific results were integrated with the outputs of climate and ecosystem models, and the expert opinion of authors, to determine the degree to which access to oceanic, coastal and freshwater fisheries resources, and the productivity of aquaculture, is likely to be affected by the changing climate {Chapter 1}. The approach used to assemble the technical information required for the vulnerability assessments involved four steps (Figure 6.1).

1. Describing the observed and projected changes to atmospheric (surface) climate in the region {Chapter 2}[11].
2. Describing the observed and projected changes to the main features of the tropical Pacific Ocean {Chapter 3}[12].
3. Assessing the way in which projected changes to the climate and ocean are likely to affect the ecosystems that support fisheries resources, i.e. the food webs in the open ocean {Chapter 4}[13], coral reefs {Chapter 5}[14], mangroves, seagrasses and intertidal flats {Chapter 6}[15], and freshwater and estuarine habitats {Chapter 7}[16].
4. Assessing the likely direct effects of projected changes to surface climate and the ocean, and the indirect effects of projected changes to ecosystems, on the abundance and distribution of species supporting oceanic fisheries {Chapter 8}[17], coastal fisheries {Chapter 9}[18], and freshwater and estuarine fisheries {Chapter 10}[19], and aquaculture production {Chapter 11}[20].

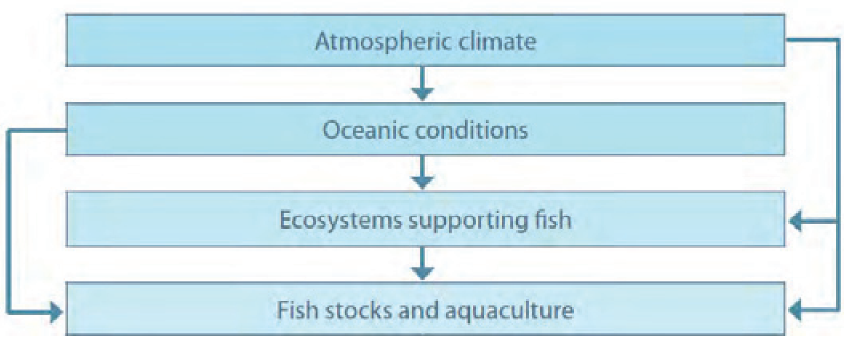


Figure 6.1 Summary of the approach used to assess the vulnerability of fish stocks and aquaculture in the tropical Pacific to climate change.

Use of climate models

Global climate models were used to provide the projections involved in Steps 1 and 2 of the approach outlined above. A climate model is a numerical description of our understanding of the physics, and in some cases chemistry and biology of the ocean, atmosphere, land surface and ice regions {Chapter 1}. Climate models with reasonable 'skill' in capturing present and past states of the climate system are the best tools we have to make projections of what the future might hold.

At its most basic level, a climate model describes (1) Newton's law that the motion of a fluid (water or air) can be determined if the forces acting on it are known (e.g. the winds pushing the surface of the ocean, or the friction trying to oppose any motion), and (2) the laws of conservation of mass and energy (e.g. if water flows into an obstacle it will be deflected, or if solar energy penetrates the ocean surface, the water will warm). In principle, we should be able to use these mathematical formulas to give a near perfect description of the real world, but in practice compromises must be made due to computational limitations.

To implement these physical laws within the architecture of even the most powerful computers, our simulation of the climate system must be greatly simplified and broken down into a collection of grid 'boxes'. For the current generation of global climate models, these boxes have a resolution in the ocean that is typically 100–200 km on each side (atmospheric resolutions are generally even coarser). This means that all ocean currents (or variations in temperature or salinity, etc.) within the area of a particular box will be represented by a single average current (temperature or salinity, etc.). Consequently, many smaller-scale processes (e.g. finer-scale circulation in coastal zones) with widths of a few kilometres are not resolved by the models. Unfortunately, these smaller scales are often the ones we are most interested in and care must be taken in 'downscaling' the projections from models to ensure they are useful in assessing regional impacts. To help address this limitation, many of the unresolved processes are 'parameterised'. These parameterisations essentially translate the effect of small-scale processes to the larger scales on which the models operate.

Model results used for the vulnerability assessments reported here are primarily from the Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model data set, which was used by the Fourth Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR4). All models are state-of-the-art 'coupled' models, meaning that ocean, atmosphere, land and ice models are coupled together, with information continuously being exchanged between these components to produce an estimate of global climate that evolves with time.

These global climate models are generally run for hundreds of simulation-years subject to constant, pre-industrial (1870) forcing, i.e. constant solar energy and appropriate greenhouse gas levels (Figure 6.2). This gives the ocean time to 'settle down' into a near equilibrium. Using the 'pre-industrial run' as a baseline, the 20th century simulations incorporate increasing greenhouse gases[i] in the atmosphere in line with historical emissions and take observed natural forcing (e.g. changes in solar radiation, volcanic eruptions) into account.

At the end of the 20th century, projection simulations are carried out based on predefined 'plausible' future emission trajectories. In our case, we focus on two of these trajectories, corresponding to low (B1) and high (A2) emissions scenarios.

Assessments are made of the ability of the models to simulate the atmosphere and ocean (for the end of the 20th century) and both near-term (2035) and long-term (2100) projections (Figure 6.2). These models are far from perfect, however, and represent only an approximation of the real world. Two different models will simulate two different climate trajectories, even when subject to the same carbon dioxide equivalent emissions, due to the use of different parameterisations and levels of approximation.

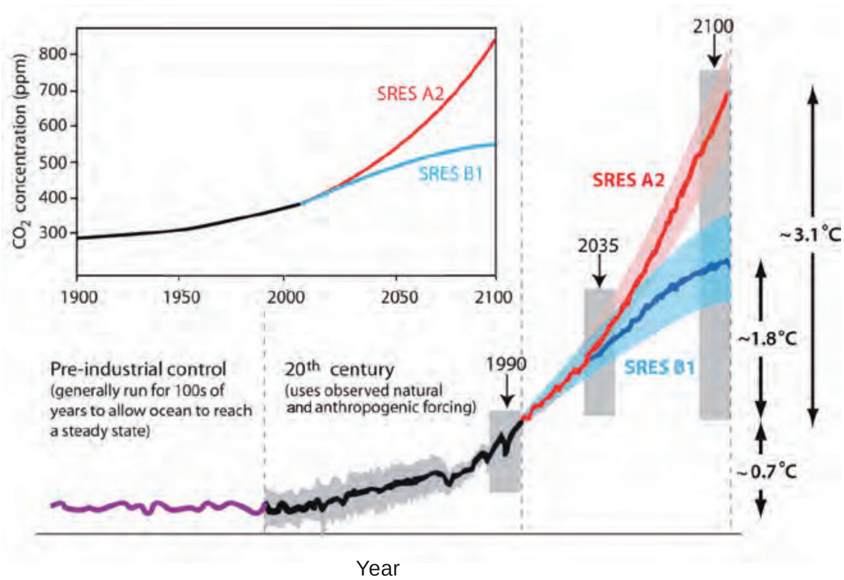


Figure 6.2 Globally averaged surface air temperature simulated by a multi-model average of the CMIP3 coupled climate models the pre-industrial period (purple), the 20th century (black), B1 emissions scenario during the 21st century (blue) and the A2 scenario in the 21st century (red). The spread associated with output from different models is highlighted by the translucent shading. Also shown are observed and multi-model average changes in surface air temperature relative to 1980–2000. Information after 1900 is based on IPCC-AR4. Inset shows the historical and future CO_2 concentrations used by the models.

The difference between models is highlighted by the spread in the projections around each of the scenarios in Figure 6.2. In general, the projected changes tend to be more certain at large spatial scales (e.g. global average temperature) but become

i Some simulations also include sulphate aerosols and ozone.

increasingly uncertain at more local scales (e.g. the strength of a particular ocean current). To overcome some of these uncertainties, the average output from suites of independent climate models with a good ability to simulate present climate was used. By averaging across multiple models many of the biases inherent in individual models were reduced. However, systematic biases still persist in some cases, so it is important to interpret model results with an awareness of their shortcomings.

Biogeochemical models

The CMIP3 models only provide projections of the physical climate and do not explicitly simulate responses of habitats and fish stocks to climate change. Such responses must be inferred from our best understanding of how productivity and higher levels of the food web react to observed climate variability. For some of the analyses, a number of biological components were coupled to one of the CMIP3 models (IPSL-CM4) to make projections of (1) primary production and the extent of the different ecological provinces in the tropical Pacific Ocean {Chapter 4}, and (2) catches of skipjack and bigeye tuna {Chapter 8}. Thus, any uncertainties associated with the IPSL-CM4 model are transferred to the simulated biological responses.

How to use the technical summaries

Sections 6.2 to 6.11 provide brief descriptions of the main technical results of the approach described in Figure 6.1. Links are provided {in curly brackets} within each technical summary to the comprehensive vulnerability assessment (published as a peer-reviewed book) for readers interested in the full details of the analyses.

6.2 Observed and projected changes in surface climate of the tropical Pacific {Chapter 2}[11]

Weather is defined as the state of the atmosphere as described from day-to-day by measurable variables, such as air temperature, rainfall, wind speed and direction, cloud cover and humidity. Climate is the long-term average weather – what is expected at a particular time and place – and is based on observations over many years. Descriptions of climate can include both the average values and measures of variability from year-to-year. Climate change is defined as a significant alteration in what we expect the weather to be like at a particular location and season. Changes occur in average values and/or in the variability around the average, i.e. the range of extremes. Projecting the nature and significance of changes in climate globally or regionally requires on long-term, uniform weather observations from as many locations as possible.

The ecosystems that Pacific Island countries and territories (PICTs) rely on for economic development, and the food security and livelihood opportunities for their people, are adapted to the prevailing climate conditions and their normal seasonal variations. Global and regional climates have varied on spatial and temporal scales in the past due to a range of forcing factors, such as ice age cycles caused by changes in the earth's orbit. Increasing concentrations of atmospheric greenhouse gases, and the associated changes in climate, have now has been linked unequivocally to human activities since the late 18th century[9]. The concentration of the main greenhouse gas, carbon dioxide (CO_2), increased from 280 parts per million (ppm) in 1750 to 385 ppm in 2008, and has continued to rise at approximately 2 ppm since then {Chapter 1}. The 38% increase in atmospheric CO_2 between 1750 and 2008 represents the highest concentration of this greenhouse gas in the last 800,000 years. The associated warming of the global climate observed during the 20th century is estimated to have occurred at a rate 10 times faster than the 4–7°C warming since the last glacial period ~ 21,000 years ago. Climate change due to human activities is not a future event, significant changes in climate have already been observed.

Observed trends in the last 50 years show increases in air temperatures, changes to atmospheric circulation and rainfall, and possible increases in cyclone intensity. Under the B1 and A2 emissions scenarios in 2035 and 2100, surface climate in the tropical Pacific region is projected to continue to warm rapidly. This warming will cause changes to atmospheric conditions and rainfall.

The present-day surface climate in the region, observed trends, and projections of how the climate of the tropical Pacific will change with continued increased emissions of greenhouse gases, are summarised below.

Present-day surface climate

Atmospheric circulation {Chapter 2, Section 2.3.1}

The surface climate of PICTs is dominated by the vast surrounding Pacific Ocean, the large-scale atmospheric circulations (Hadley and Walker Circulations) and the ocean currents associated with the northeast and southeast trade wind regimes. The atmospheric circulations from the two hemispheres meet in the Intertropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ). The SPCZ is one of the most significant features of tropical and subtropical climate in the Southern Hemisphere. It is characterised by a convergence of air flow leading to uplift and a band of clouds and rainfall stretching from the Western Pacific Warm Pool (Warm Pool) (Section 6.3) in the western Pacific southeast towards French Polynesia. The atmospheric and oceanic conditions are also at the heart of the major source of interannual climate variability in the tropical Pacific – El Niño-Southern Oscillation (ENSO) events.

Air temperature {Chapter 2, Section 2.3.2}

The tropical Pacific consists primarily of ocean, with extremely small land areas {Chapter 1, Table 1.1}, and therefore the mean air temperatures are dominated by average sea surface temperatures (SSTs). SSTs are similar to air temperatures for low-lying land areas and are a good proxy for surface air temperatures. In general, average SSTs are warmer in the western Pacific compared to the eastern Pacific. The annual maximum SST of the Warm Pool is ~ 30°C {Chapter 3} (Section 6.3).

Seasonal variation in temperatures and rainfall {Chapter 2, Section 2.3.3}

The equatorial areas of the Pacific experience very small annual variations in air temperature and SST. For example, the annual range of SSTs is < 2°C throughout much of the western tropical Pacific. The annual ranges of air temperature and SST increase with latitude in the Southern Hemisphere. The greatest annual variability in air temperature and SST in the region occurs in subtropical areas. Maximum rainfall occurs in the austral summer, a pattern that is strongest between 10°S and 20°S. However, at higher (subtropical) latitudes, there is little seasonality in monthly rainfall.

Tropical cyclones {Chapter 2, Section 2.3.4}

Tropical cyclones occur mainly in subtropical areas during the respective summer seasons and are rarely observed within about 5–10° of the equator. Tropical cyclones bring strong winds, high rainfall, and destructive storm surges to the southwest, northeast and northwest tropical Pacific. In the southwest Pacific, tropical cyclones usually develop during the austral summer season, from November to April, but occasionally occur in May. Peak cyclone occurrence is usually from January to March. About half of the storms that develop in the tropical Pacific reach cyclone force with mean wind speeds of > 118 km/h. Regionally, the highest frequencies of tropical cyclones occur between New Caledonia and Vanuatu in the Coral Sea, and towards Fiji.

Climate variability in the tropical Pacific {Chapter 2, Section 2.3.5}

Various sources of natural variability are superimposed on the seasonal cycles and observed trends in surface climate. This variability modulates atmospheric and ocean climate on time scales of weeks to decades. ENSO is the main source of interannual global climate variability and is centred in the tropical Pacific. ENSO fluctuates between two phases, El Niño and La Niña, with large parts of the tropical Pacific experiencing significantly warmer-than-normal SSTs during El Niño events. Conversely, significantly cooler SSTs occur during La Niña events. Different patterns of rainfall are also associated with the two phases of ENSO. The interannual variability of ENSO is modulated by the Pacific Decadal Oscillation (PDO) on decadal time scales. The PDO causes distinct anomalies in the warm or cool phases of Pacific SST which can persist for several decades. The Southern Annular Mode (SAM) is the most important source of variability in the atmospheric circulation of mid to high (temperate) latitudes. SAM fluctuates between two phases that influence the strength of the westerly winds of the Southern Ocean as well as sea-level and ocean circulation patterns in the southern Pacific Ocean, including subtropical areas {Chapter 3}, on time scales longer than ~ 50 days.

Observed trends in surface climate

Air temperature {Chapter 2, Section 2.4.1}

Observational records show that tropical Pacific air temperatures over the islands have already warmed significantly and that the rate of warming has accelerated in recent decades. Observed average global land temperatures have warmed ~ 0.7–0.8°C over the past 100 years and the rate of warming has accelerated over the past 50 years. Although warming of air temperatures in PICTs has not been as great as over land at higher latitudes, the tropical Pacific is still warming at ~ 70% of the global average rate.

Rainfall {Chapter 2, Section 2.4.2}

There have been some significant changes in the observed annual and daily rainfall climate of the southwest tropical Pacific, primarily on islands east of 160°W. Changes in rainfall to the west have tended to be small and incoherent. Generally, over the period 1961–2000, there has been more rainfall and more intense rainfall northeast of the SPCZ and less rainfall to the southwest of the SPCZ.

South Pacific Convergence Zone {Chapter 2, Section 2.4.3}

Long-term variations in the position of the SPCZ do not show any significant change over the period 1890–2005. There are, however, decadal variations in the position of the SPCZ that closely align with the warm and cool phases of the PDO and ENSO. These variations significantly affect rainfall patterns throughout the southern tropical Pacific.

Tropical cyclones {Chapter 2, Section 2.4.4}

On average, there are nine tropical cyclones in the southwest Pacific per year. There has been no discernible trend in the frequency of tropical cyclones in the southwest Pacific over the past 30 years, and no evidence yet for any significant change in the intensity of cyclones in the region.

Projected changes in surface climate

Near-term (2035) and long-term (2100) projections of tropical Pacific surface climate for low (B1) and high (A2) emissions scenarios are based on averaging projections from several global climate models {Chapter 1, Section 1.8.2; Chapter 2, Section 2.5}. Given that none of these complex models are perfect, this averaging procedure emphasises changes that are common among different models and identifies areas/variables where projected changes cannot be made with confidence due to model disagreement. Projections resulting from the multi-model averages for the main features of surface climate are summarised below (Table 6.1).

Air temperature {Chapter 2, Section 2.5.1}

Surface air temperatures in the tropical Pacific are projected to continue their observed warming trend. By 2035, air temperatures are likely to be 0.5–1.0°C higher than the 1980–1999 average. By 2100, the increase is expected to be 1.0–1.5°C under the B1 emissions scenario and 2.5–3.0°C under the A2 scenario.

Rainfall {Chapter 2, Section 2.5.2}

There is more uncertainty between the different climate models as to how rainfall patterns will change across the tropical Pacific. However, it seems likely that rainfall will increase in the convergence zones near the equator and decrease in the subtropics. Warming oceans are expected to intensify the hydrological cycle, which is likely lead to more extreme rainfall events and, given warmer air temperatures, more intense droughts.

El Niño-Southern Oscillation {Chapter 2, Section 2.5.3}

It is still uncertain how the frequency and/or intensity of ENSO events may change in a warming world. Nevertheless, ENSO events are likely to continue to be a major source of interannual climate variability in the tropical Pacific.

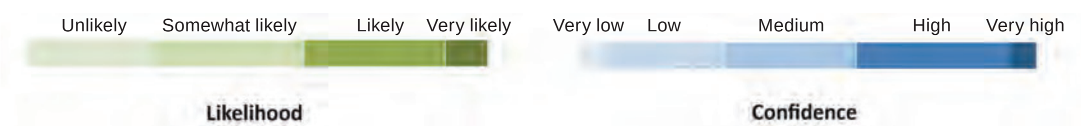
Tropical cyclones {Chapter 2, Section 2.5.4}

There may be fewer tropical cyclones in the region in the future but those that do occur are likely to be more intense. The location of tropical cyclone activity is not projected to change significantly.

Table 6.1 Summary of projected changes to tropical Pacific surface climate relative to average values for 1980–1999. Recent and projected concentrations of atmospheric carbon dioxide (CO_2) are also shown.

Variable		1980–1999 average	Projected change			
			B1 2035	A2 2035	B1 2100*	A2 2100
Air temperature (°C)		27.4	+0.5 to +1.0	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall	Equatorial	n/a	+5 to +15%	+5 to +20%	+10 to +20%	+10 to +20%
	Subtropics		-5 to -10%	-5 to -20%	-5 to -20%	-5 to -20%
ENSO events		Interannual variable	Continued source of interannual climate variability			
PDO-decadal variability		Decadal variable	Continued source of decadal modulation in Pacific basin climate and ENSO events			
Tropical cyclones		9	➢ Total number of tropical cyclones may decrease ➢ Cyclones are likely to be more intense			
Atmospheric CO_2 (ppm)		339–368	400–450	400–450	500–600	750–800

* Approximates A2 in 2050; ENSO = El Niño-Southern Oscillation; PDO = Pacific Decadal Oscillation; n/a = data not available.



6.3 Observed and projected changes to the tropical Pacific Ocean {Chapter 3}[12]

The fish and invertebrates harvested in the tropical Pacific depend intimately on the oceanic environment. Large- and small-scale circulation patterns influence larval dispersal and the migration of species; and water temperature, salinity, nutrient availability, dissolved oxygen concentration and pH affect biological activity. Oceanic currents, waves and sea level also shape the coastal habitats on which many fish species depend.

The main features of the tropical Pacific Ocean, recent observed changes in these features, and projections of how the ocean will change with continued forcing due to increasing greenhouse gases, are summarised below.

Features of the tropical Pacific Ocean

Large-scale ocean currents {Chapter 3, Section 3.2.1}

The main currents in the tropical Pacific Ocean (Figure 6.3) are driven by the southeast trade winds. Due to the interaction between the trade winds and the Coriolis force, surface waters near the equator are driven poleward by 'Ekman transport' to subtropical latitudes. Waters at latitudes higher than 25°S and 25°N are forced towards the equator by westerly winds. The convergence of the water bodies moving in different directions produces two west-flowing currents: the North Equatorial Current (NEC) and the South Equatorial Current (SEC). These currents are diverted when they encounter islands and land, feeding a number of smaller currents and undercurrents, and the Warm Pool. The NEC and SEC are also altered by the presence of the Intertropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ). These convergence zones alter local wind conditions, resulting in two east-flowing counter currents; the North Equatorial Counter Current (NECC) under the ITCZ, and the South Equatorial Counter Current (SECC) under the SPCZ. The boundaries where the westward currents and eastward counter currents meet create eddies that can cause upwelling of nutrient-rich water. Currents in the southeast Pacific remain fairly constant throughout the year, whereas currents in the western Pacific vary in intensity and direction due to season and ENSO.

Ocean temperature {Chapter 3, Section 3.2.2}

Sea surface temperature (SST) in the tropical Pacific Ocean varies spatially and temporally. Spatial deviations occur where winds move surface waters or cause upwelling. For example, the southeast trade winds push warm water to the western Pacific, forming the Warm Pool. The world's warmest oceanic temperatures occur in the Warm Pool, which is defined by SSTs greater than 28°C. The prevailing southeast trade winds along the equator also cause upwelling that brings deep, cool, nutrient-rich waters to the surface, reducing SSTs. Seasonal changes in SST near the equator are weak and interannual variations are limited to 2 to 3°C. Seasonal variation in SST is greatest away from the equator, where it can vary by up to 7°C throughout the year.

The temperature of the tropical Pacific Ocean also varies with depth, declining as depth increases. The warmer surface water also has a lower density than the deeper cooler waters. Where the two layers meet at the 'thermocline', the water temperature changes rapidly. In the tropical Pacific Ocean, the thermocline usually lies in the upper 500 m and the temperature across the thermocline drops by 20°C.

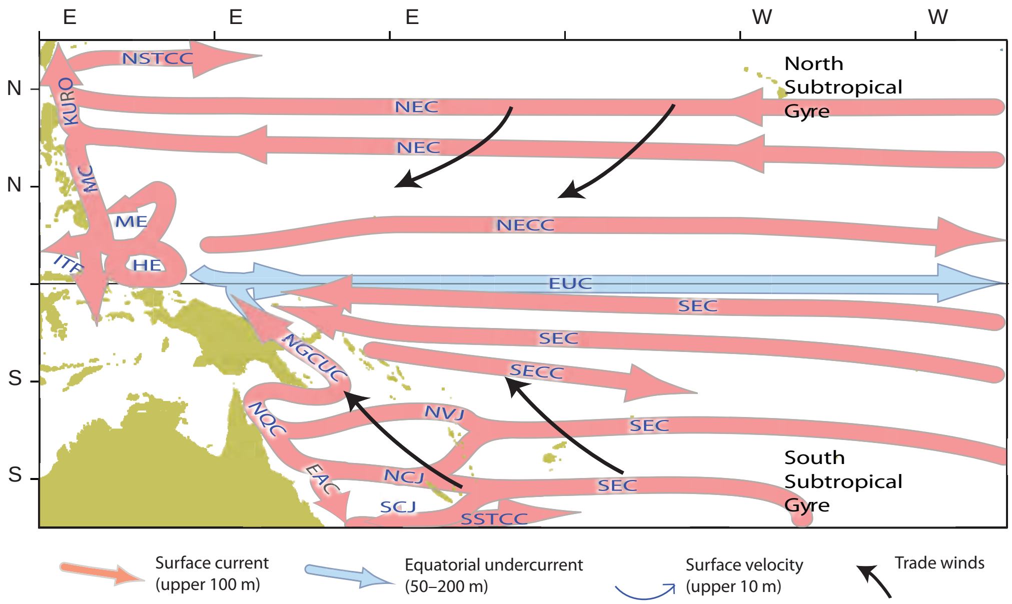


Figure 6.3 The main ocean currents in the upper 100 to 200 m of the water column. Currents shown are: North Subtropical Counter Current (NSTCC); Kuroshio Current (KURO); Mindanao Current (MC); Mindanao Eddy (ME); Halmahera Eddy (HE); North Equatorial Current (NEC); North Equatorial Counter Current (NECC); Equatorial Undercurrent (EUC); Indonesian Throughflow (ITF); New Guinea Coastal Undercurrent (NGCUC); North Queensland Current (NQC); East Australian Current (EAC); North Vanuatu Jet (NVJ); North Caledonian Jet (NCJ); South Caledonian Jet (SCJ); South Equatorial Counter Current (SECC); South Equatorial Current (SEC) and South Subtropical Counter Current (SSTCC).

Ocean eddies {Chapter 3, Section 3.2.3}

Eddies in ocean, and in coastal areas, can draw nutrient-rich water from the deeper layers of the ocean towards the surface, stimulating primary production {Chapter 4, Box 4.1}. Eddies also transport heat, nutrients, particles and larval fish and invertebrates at local scales. The size of eddies depends strongly on latitude – in the tropical Pacific they range from ~ 150 to 300 km in diameter. The passage of eddies is associated with important variations in local currents, sea surface height and the vertical structure of the water column.

Nutrient supply {Chapter 3, Section 3.2.4}

Biological processes (e.g. photosynthesis by phytoplankton) at the ocean surface deplete the supply of nutrients. Consequently, concentrations of nutrients are much greater at depths of > 100 m than at the surface. Ocean circulation, or deep mixing of the water column, is needed to transfer nutrients back to the surface. However, the strong density stratification in the Pacific Ocean inhibits the vertical exchange of water (and therefore nutrients) between the deep and shallow layers of the ocean. The main processes that can overcome the stratification barrier and deliver nutrient-rich water to the upper layers are turbulence in the surface mixed layer, wind-driven upwelling, and eddies.

Dissolved oxygen {Chapter 3, Section 3.2.5}

Dissolved oxygen (O_2) levels in surface waters of the tropical Pacific Ocean are determined by (1) the rate of oxygen transfer from the atmosphere (which is dependent on SST); (2) the rate oxygen is produced from photosynthesis; and (3) the rate at which the oxygen-rich surface waters are submerged via ocean currents and mixing. At high latitudes, cold surface waters rich in oxygen are pushed to lower latitudes, below lighter subtropical waters. These waters gradually lose O_2 as organic matter is remineralised by bacteria. The concentration of O_2 at any point in the water column is a balance between the original O_2 content, the effect of remineralisation of organic matter by bacteria, and the rate at which water is replaced through ocean circulation. In regions of high bacterial activity, consumption of O_2 can exceed replenishment from ocean circulation, causing oxygen depletion and anoxic conditions.

Ocean acidification {Chapter 3, Section 3.2.6}

The acidity of the ocean has been relatively stable for millions of years. Due to this stability, carbonate ions are naturally abundant and the common pure minerals of calcium carbonate (aragonite and calcite) are formed in surface waters and do not dissolve. The pH of the ocean is related to the amount of carbon dioxide in the atmosphere {Chapter 3, Box 3.3}. Average ocean pH is now ~ 8.1. Ocean pH varies seasonally and spatially by ~ 0.3 units due to changes in SST and upwelling of deep waters rich in carbon dioxide.

Wave height {Chapter 3, Section 3.2.7}

The size of surface waves on the ocean depends on the strength of the wind, the distance over which the wind blows, the length of time the wind has been blowing and the water depth. Waves have a major influence on ocean surface mixing, sediment suspension and transport. In the tropical Pacific Ocean, model simulations show that average significant wave height ranges from 1.5 to 2.5 m, and generally decreases to the west. There are large natural variations in the wave conditions of the tropical Pacific Ocean due to storm activity and large-scale climate patterns, such as ENSO.

Sea level {Chapter 3, Section 3.2.8}

Sea level at a given location is determined by a number of factors that vary in time and space. Tides affect sea level on a predictable periodic basis, the effects of storms and eddies are episodic and can last from hours to days, and circulation changes (like those associated with ENSO) can cause large interannual variation. The interaction of these factors causes substantial variation in sea level. For example, regional changes in sea level due to ENSO events can be as great as 20 to 30 cm.

Coastal circulation and island effects {Chapter 3, Section 3.2.9}

Regional oceanic processes that occur along coastlines and around islands also influence the features of the coastal environment at local scales. There is considerable variation in circulation (e.g. currents and eddies), SST, nutrient supply and ultimately productivity, among coastal areas across the region.

Recent observed changes in the tropical Pacific Ocean

Large-scale currents and eddies {Chapter 3, Sections 3.3.1 and 3.3.3}

The intensity of ocean circulation caused by the South Pacific Subtropical Gyre and the SEC increased between 1993 and 2003, presumably due to the combined effects of natural variability and global warming. As a result, sea level at the centre of this gyre has increased by 12 cm. The North Pacific Subtropical Gyre also intensified over this period but with weaker amplitude. Eddy activity in the tropical Pacific Ocean between 1993 and 2001 varied by 15–30%. In general, there were stronger interannual changes in the occurrence and distribution of eddies.

Ocean temperature {Chapter 3, Section 3.3.2}

In the past 50 years, average annual SST has increased by > 1°C in the southwest and northeast of the tropical Pacific. The warming reached a depth of 200 m at several latitudes and has been as great as 2°C in some locations.

Nutrient supply {Chapter 3, Section 3.3.4}

The two longest time-series of oceanographic data in the tropical northern Pacific, spanning 30 years, indicate that there has been a slight decrease in nutrient supply over this period. This trend is consistent with increased stratification caused by a warming ocean. However, the data are insufficient to establish whether a basin-scale trend is occurring. Trends in nutrient supply to the surface layer of the ocean due to climate change are still difficult to gauge because of the strong influence of ENSO and PDO.

Dissolved oxygen {Chapter 3, Section 3.3.5}

A major westward expansion of the oxygen-minimum waters in the eastern Pacific basin has been detected over the past 50 years. The thickness of the oxygen-poor layer has also increased over this time in the Pacific Equatorial Divergence Province. These observations are consistent with climate projections. Lower oxygen concentrations can have consequences for ecosystems {Chapter 4} and the distribution of tuna {Chapter 8}.

Ocean acidification {Chapter 3, Section 3.3.6}

Increased emissions of carbon dioxide have decreased the pH of the tropical Pacific Ocean by 0.06 pH units since the beginning of the industrial era. The current rate of decrease is ~ 0.02 units per decade and is unprecedented in the past 300 million years. The aragonite saturation level (related to acidification of the ocean) is close to the point where calcareous organisms, such as corals and a number of planktonic species, may already be experiencing a weakening in their skeletons and shells. These changes are likely to reduce the fitness of calcareous organisms and their resistance to predation.

Wave height {Chapter 3, Section 3.3.7}

Around the world, visual reports from shipping show an increase in significant wave heights (SWH) at mid- and high-northern latitudes since 1950. However, in the far western part of the Warm Pool, SWH has decreased at a rate of 8 cm per decade. There are insufficient data from other parts of the tropical Pacific Ocean to determine whether SWH has changed over recent decades.

Sea level {Chapter 3, Section 3.3.8}

Sea level has risen by ~ 17 cm globally since pre-industrial times and 6 cm since 1960. The rate of increase appears to be accelerating due to more rapid ice melt and thermal expansion of the upper ocean. Based on long-term tide gauge data in the tropical Pacific Ocean sea level is currently rising by ~ 2.5 cm per decade.

Coastal circulation and island effects {Chapter 3, Section 3.3.9}

Changes in the strength and location of mesoscale upwellings close to coasts are likely to have occurred due to changes in the wind field and/or thermal structure of the ocean. However, such changes have not been quantified.

Projected changes in the tropical Pacific Ocean

The projected changes to the main features of the tropical Pacific Ocean are outlined below and summarised in Table 6.2.

Large-scale currents and eddies {Chapter 3, Sections 3.3.1 and 3.3.3}

The currents in the tropical Pacific Ocean are expected to change due to global warming, particularly near the equator. The flow of the SECC is projected to decrease by 8% under the B1 scenario, and 18% under A2, in 2035. By 2100, flow of the SECC is expected to reduce by 28% under B1 and 60% under A2. The SEC is projected to decrease in strength by 3–5% under B1 and A2 in 2035 and by 8–18% in 2100, with corresponding reductions in SEC transport (volume of water dispersed). The Equatorial Undercurrent (EUC) is expected to increase in strength and transport by 2100, reducing the depth penetration of the SEC. In the Northern Hemisphere, a decrease is projected in the eastern half of the NECC, with a slight decrease in the NEC. Eddy activity can be expected to increase or decrease in association with projected changes in current strength.

Ocean temperature {Chapter 3, Section 3.3.2}

Ocean temperature is expected to continue rising substantially, with higher warming rates near the surface, especially in the first 100 m. SST is expected to increase by 0.7°C in 2035, 1.4°C in 2100 under the B1 emissions scenarios, and 2.5°C under A2. The salinity of the tropical western Pacific Ocean is projected to decrease due to the intensified hydrological cycle {Chapter 2}. The salinity front associated with the Warm Pool is likely to extend further east by ~ 2000 km, while the 29°C isotherm is expected to move further east at the equator. The area of the Warm Pool with SST > 29°C is projected to expand by 250% by 2035 and > 700% by 2100 under the A2 emissions scenario.

Nutrient supply {Chapter 3, Section 3.3.4}

Projected changes to physical features of the ocean that control the supply of nutrients, include stratification; maximum depth of the mixed layer during winter; upwelling or downwelling at a depth of 50 m; and the areas where currents converge. For the region as a whole, stratification is expected to increase by ~ 10% for both scenarios in 2035, compared with the 1980–1999 average. In 2100, the increase in stratification is projected to be 10% to 20% for the B1 scenario, and 20% to 30% for A2, with the greatest changes in the Warm Pool. The mixed layer depth is projected to be shallower. Minor decreases in upwelling at the equator, and downwelling in adjacent waters, are expected to occur but should not affect the supply of nutrients substantially in the Pacific Equatorial Divergence Province. The major projected change to convergence of currents occurs in the region of the SECC (around 8°S), where the area of eastward flow near the surface is expected to retract west by about 1500 km in 2100 under the A2 scenario.

Table 6.2 General summary of observed and projected changes to the main features of the tropical Pacific Ocean. Observed changes are relative to the period 1950–1960. Projected changes are relative to 1980–1999. Estimates of confidence are provided for each projection (see key below).

Ocean feature	Observed changes	2035		2100	
		B1	A2	B1	A2
Currents	South Pacific gyre has strengthened	SEC decreases at the equator; EUC becomes shallower; SECC decreases and retracts westward in the upper 50 m			
Sea surface temperature		Projected to increase significantly over the entire region			
		+0.6 to +0.8°C	+0.7 to +0.8°C	+1.2 to +1.6°C	+2.2 to +2.7°C
Ocean temperature at 80 m	+0.6 to 1°C since 1950	+0.4 to +0.6°C		+1.0 to +1.3°C	+1.6 to +2.8°C
Warm Pool	Warmer and fresher	Extends eastward; water warms and becomes fresher, and area of warmest waters increases			
Equatorial upwelling	Decreased	Integral transport 9°S–9°N remains unchanged			
Eddy activity	No measurable changes	Probable variations in regions where major oceanic currents change			
Nutrient supply	Decreased slightly in two locations	Decrease due to increased stratification and shallower mixed layer, with a possible decrease of up to 20% under A2 by 2100			
Dissolved oxygen	Expansion of low-oxygen waters	Possible decrease due to lower oxygen intake at high latitudes Possible increase near the equator due to decreased remineralisation			
Ocean acidification		Aragonite saturation (Ω) projected to continue to decrease significantly			
	➢ Ω decreased from 4.3 to 3.9	n/a	Ω ~ 3.3	Ω ~ 3.0	Ω ~ 2.4
	➢ Ω horizon rises from 600 to 560 m	n/a	~ 456 m	n/a	~ 262 m
	➢ pH decreased from 8.14 to 8.08	n/a	~ 7.98	n/a	~ 7.81
Waves	Decreased in far west Pacific; no data elsewhere	Slight increase (up to 10 cm) in swell wave height; patterns depend on ENSO and tropical cyclones			
Sea level	+6 cm since 1960	Projected to rise significantly			
		*	+8 cm	+18 to +38 cm	+23 to +51 cm
		**	+20 to +30 cm	+70 to +110 cm	+90 to +140 cm
Island effects	Not observed	Probable; undocumented			

* Projections from the IPCC-AR4, not including any contribution due to dynamical changes of ice sheets; ** projections from recent empirical models (Section 3.3.8.2); SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current; ENSO = El Niño-Southern Oscillation; n/a = estimate not available.

Dissolved oxygen {Chapter 3, Section 3.3.5}

Dissolved oxygen is expected to decline in many parts of the region due to larger-scale processes occurring at higher latitudes. In particular, the increasing temperature and stratification of the ocean at higher latitudes are projected to lead to decreased transfer of O_2 from the atmosphere to the ocean, resulting in lower concentrations of O_2 in the tropical thermocline. The existing low levels of O_2 and suboxic areas in the eastern Pacific are also expected to intensify. In contrast, increased concentrations of O_2 are projected to occur in the equatorial thermocline due to reduced biological production (and therefore remineralisation/oxidation) within the water masses flowing to the equator.

Ocean acidification {Chapter 3, Section 3.3.6}

Increases in atmospheric carbon dioxide are projected to lead to substantial additional acidification of the ocean, reducing the average pH of the ocean by 0.2–0.3 units under the B1 and A2 scenarios by 2100. At such rates of change, aragonite saturation levels in the tropical Pacific Ocean are expected to fall below 3.25 under A2 by 2035. The aragonite saturation level is expected to decrease to 2.4 under A2 in 2100. The average depth of the aragonite saturation horizon {Chapter 3, Box 3.3} in the region has been 300 m at 8°N, and deeper to the south and to the north. The horizon is projected to become shallower over time, reaching 150 m in 2100 under the A2 scenario.

Wave height {Chapter 3, Section 3.3.7}

An increase in SWH of 8 to 10 cm in the southern tropical Pacific is projected for 2100 under the A2 emissions scenario. This increase is expected to be most pronounced in the east. No change or a decrease of about 4 cm is expected by 2100 in the northern tropical Pacific. The 20-year return SWH (the value that significant wave height exceeds at least once over a 20-year period) is projected to increase by about 30 cm in the eastern half of the southern tropical Pacific under A2 in 2100. The nature of future ENSO events is also expected to affect wave height.

Sea level {Chapter 3, Section 3.3.8}

The rate of sea-level rise is expected to accelerate. Projections from IPCC-AR4 that sea level will rise by up to 18 cm under B1, and up to 51 cm under A2, by 2100 are now considered to be conservative because they do not include the effects of increased flow from the melting of land ice. Some projections based on historical reconstructions for global sea-level rise, which include the effects of ice melt and thermal expansion, indicate that sea-level rise could be 20 to 30 cm under the B1 and A2 scenarios in 2035, 70 to 110 cm under B1 in 2100 and 90 to 140 cm under A2 in 2100. However, this estimate should be used with caution until the limitations of the methods involved are better understood[ii].

Coastal circulation and island effects {Chapter 3, Section 3.3.9}

Climate change is expected to have localised effects on the waters surrounding different islands through interactions between large-scale oceanic and atmospheric processes and island topography. However, the necessary local projections are scarce and there is a need for specific studies to downscale future climate simulations {Chapter 3, Section 3.5}.

ii See 'Climate Change in the Pacific: Scientific Assessment and New Research' (www.cawcr.gov.au/projects/PCCSP) for other estimates of sea-level rise.

6.4 Vulnerability of open ocean food webs in the tropical Pacific to climate change {Chapter 4}[13]

The tropical Pacific Ocean represents a vast area of fish habitat, dwarfing the total area of land {Chapter 1} and associated coastal fish habitats {Chapters 5 and 6} under the jurisdiction of Pacific Island countries and territories (PICTs).

Although much of this open ocean domain is relatively unproductive, it supports some of the largest tuna fisheries in the world. Recent catches of skipjack tuna, yellowfin tuna, bigeye tuna and South Pacific albacore from the Western and Central Pacific Ocean (WCPO) have been ~ 2.5 million tonnes per year, representing > 25% of the total global tuna catch {Chapters 1, 8 and 12}.

The production of the four species of tuna, and other large pelagic fish, is underpinned by food webs based not only on the direct photosynthetic productivity of phytoplankton (primary production) in the sunlit surface layer (photic zone) of the ocean, but also by detritus and bacteria, derived from phytoplankton. Most of this primary production occurs where nutrients, such as nitrogen, phosphorus and silicon, are transported to surface waters from the deeper layers of the ocean by physical processes {Chapter 3}.

The energy produced through primary production moves through a 'trophic pyramid' via a range of zooplankton (such as copepods and larval fish), macrozooplankton (including jellyfish and salps) and micronekton (such as squid, shrimp and small fish), to sustain tuna and other large pelagic fish. Changes in ocean processes that deliver nutrients to the photic zone, and to the physical and chemical properties of the ocean, are expected to affect phytoplankton, zooplankton and micronekton.

Not surprisingly, the vast area of the tropical Pacific Ocean does not provide a uniform habitat for the organisms comprising the food webs for tuna. Instead, the region is divided into five ecological provinces, called the Pacific Equatorial Divergence (PEQD), Western Pacific Warm Pool (Warm Pool), North Pacific Tropical Gyre (NPTG), South Pacific Subtropical Gyre (SPSG) and Archipelagic Deep Basins (ARCH) (Figure 6.4). The borders of these provinces are generally defined by convergence zones of surface currents, and each province has a specific wind regime and vertical hydrological structure. The locations of PEQD and the Warm Pool change from year to year, depending on prevailing El Niño-Southern Oscillation (ENSO) conditions.

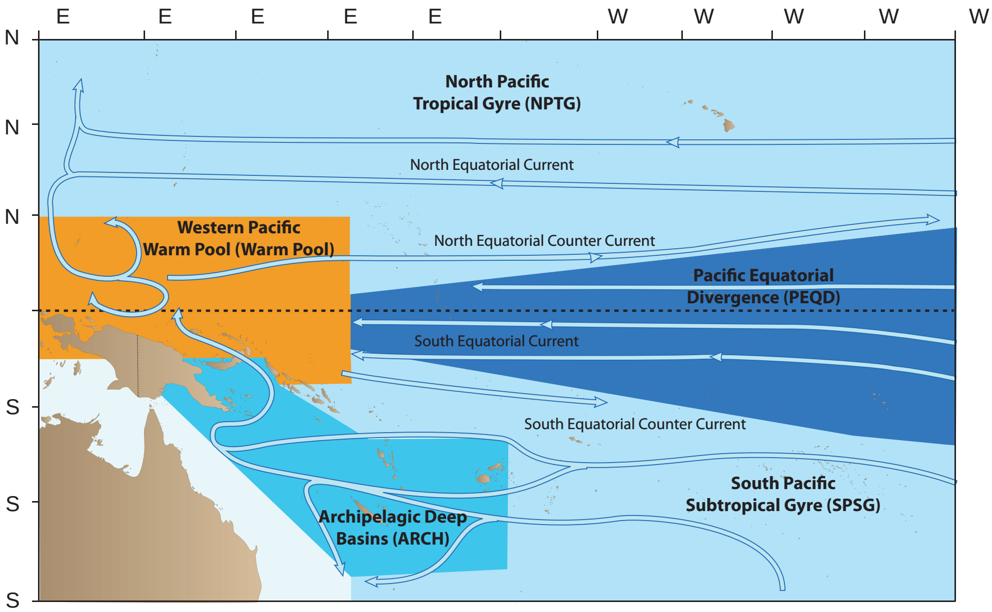


Figure 6.4 The five ecological provinces of the tropical Pacific Ocean together with the major ocean currents of the region.

Physical nature of the provinces in the region {Chapter 4, Section 4.3}

Pacific Equatorial Divergence

PEQD is generated by the effects of the earth's rotation (Coriolis force) on the South Equatorial Current (SEC) in the two hemispheres {Chapter 3}. There is significant upwelling of nutrients, creating the richest surface waters in the region. The waters of PEQD are characterised by higher salinity, partial pressure of carbon dioxide (pCO_2), nutrient concentrations and phytoplankton abundance (chlorophyll *a*). These nutrient-rich waters span much of the equatorial Pacific and drift polewards before submerging at the convergence with the North Equatorial Counter Current (NECC) and the South Equatorial Counter Current (SECC). Although the nutrients available in PEQD exceed those needed for prolific growth of phytoplankton, primary production is limited by low concentrations of iron. Therefore, regardless of the level of macronutrients, phytoplankton biomass remains relatively constant.

Western Pacific Warm Pool

The surface waters of the Warm Pool have a significantly lower salinity than PEQD, due to high rainfall {Chapter 2}. The Warm Pool is also nutrient poor because there is no upwelling. The thermocline in the Warm Pool is relatively deep (~ 80 m) under average conditions, but becomes shallower (~ 40 m) during El Niño episodes. When this occurs, there is an increase in primary production, stimulated by the supply of more nutrients to the photic zone below the thermocline.

North Pacific Tropical Gyre and South Pacific Subtropical Gyre

NPTG and SPSG are created by the large atmospheric anticyclones in the northern and southern subtropical Pacific, which generate oceanic gyres. These two provinces are characterised by a very deep but weak thermocline, which allows some nutrient inputs to the photic zone from deep water through mixing and diffusion. However, during summer, a strong and shallower (40–60 m) thermocline is superimposed on the main thermocline, creating an effective barrier to nutrient inputs. This leads to lower primary production in the upper part of the photic zone in summer.

Archipelagic Deep Basins

As the name implies, ARCH is characterised by the occurrence of many archipelagos and seamounts. It is a patchwork of processes, on a variety of spatial scales, with varied vertical structures, driven by the way the landmasses divert surface currents and create eddies (Chapter 3). ARCH also receives nutrients via runoff from high islands.

Projected changes to key physical and chemical features of provinces {Chapter 4, Section 4.7}

Climate change is likely to have three main effects on the surface areas of provinces under the B1 and A2 scenarios (1) the area of PEQD is expected to be reduced by 20–27% in 2035, 30% under B1 in 2100 and 50% under A2 in 2100; (2) the area of the Warm Pool is projected to increase correspondingly by 18–21% in 2035, and 26% and 48% under B1 and A2, respectively, in 2100; and (3) the gyres are expected to expand towards the poles and to the west.

For all provinces, the average mixed layer depth (MLD) is projected to decrease under both scenarios in 2035 and 2100, except for PEQD (which is dominated by upwelling). A decreasing MLD is expected to reduce nutrient inputs into the photic zone in the gyres and ARCH.

Ubiquitous warming of the region is projected to increase stratification {Chapter 3} in all provinces except PEQD, inhibiting the supply of nutrients. Enhanced warming of the equatorial region is expected to reduce the upwelling of deep, nutrient-rich water, and result in a contraction of PEQD. This contraction is expected to be most pronounced in the A2 scenario and likely to cause a decrease in net primary production across the entire equatorial Pacific by 2100 under high emissions of CO_2.

Dissolved oxygen (O_2) is projected to decrease by up to 26% in PEQD to a depth of 300 m by 2100 under the A2 scenario, and increase by 7–8% in NPTG by 2100 under the B1 and A2 scenarios. Elsewhere, changes to O_2 at 300 m are minor and, in all provinces except PEQD, percentage saturation of O_2 is expected to be 50–75%. In PEQD, however, it is projected to drop to 22–28%.

Ocean acidification is expected to affect all provinces, resulting in decreases in aragonite saturation (Ω) levels {Chapter 3}. Depending on the emissions scenario, the projected decrease of Ω ranges between 8% and 35%.

Projected vulnerability of food webs in provinces to key features of the ocean {Chapter 4, Section 4.8}

The vulnerability of food webs for tuna in different provinces to projected changes in the tropical Pacific Ocean in terms of their exposure and sensitivity, the potential impact of these changes, and their capacity to adapt is summarised below.

Sea temperature {Chapter 4, Section 4.8.1}

The organisms that comprise the food webs for tuna in all provinces are expected to be highly exposed to projected increases in sea surface temperature and the temperature deeper in the water column (Section 6.3). Food web organisms are sensitive to increasing water temperatures in two ways (1) their metabolism and respiration increases then plateaus and declines when temperatures exceed threshold levels; and (2) increasing stratification at higher temperatures reduces the supply of nutrients required for primary production. Food web organisms that undergo daily vertical migrations {Chapter 4, Box 4.2} have considerable capacity to adapt to these changes because they are already exposed to high variation in temperature. Other organisms are expected to occur in greater abundance where temperature ranges are more favourable. However, adapting to reductions in nutrient supply will be difficult for many organisms (see below). Overall, changes in community composition can be expected.

Mixed layer depth (MLD) {Chapter 4, Section 4.8.2}

The projected shoaling (shallowing) of the MLD, and resulting declines in nutrient supply from deeper water, are expected to affect the food webs supporting tuna, particularly in the NPTG and SPSG Provinces {Chapter 4, Section 4.7}. The potential impacts are a reduction in the average size and total biomass of phytoplankton, leading to a greater number of trophic links and less efficient food webs. Phytoplankton are unlikely to be able to adapt to reduced nutrients and shifts in community composition are expected.

Upwelling {Chapter 4, Section 4.8.3}

The food web in the PEQD Province is not projected to be exposed to major changes in upwelling. However, the food web in PEQD may benefit from increases in iron concentrations due to the projected strengthening of the Equatorial Undercurrent

{Chapter 3}. Increases in iron concentrations would help overcome the present limitation to primary production and increase the size of phytoplankton, resulting in a more efficient food web with fewer trophic links.

Solar radiation {Chapter 4, Section 4.8.4}

The Warm Pool, ARCH and PEQD provinces are expected to be exposed to projected lower levels of light due to increasing cloud cover associated with the altered hydrological cycle (Section 6.2). In contrast, SPSG and NPTG are expected to be exposed to higher light levels. Primary production in all ocean provinces is sensitive to changes in light because photoinhibition influences photosynthesis and usually occurs in the upper 30 m of the ocean. However, the potential impacts are expected to be minimal because net primary production is also determined by nutrient concentrations. Nevertheless, changes in the structure of phytoplankton and zooplankton communities can be expected as phytoplankton redistribute to depths with optimal light levels for photosynthesis.

Dissolved oxygen {Chapter 4, Section 4.8.5}

Although many organisms in the food web of each province are highly sensitive to dissolved oxygen levels, the potential impacts are projected to be minimal (except in PEQD) because oxygen concentrations are high enough to allow for some decrease without affecting productivity. The larger organisms (macrozooplankton and micronekton) living in the deeper layers are expected to be able to escape anoxic conditions by vertical migration {Chapter 4, Box 4.2}.

Ocean chemistry {Chapter 4, Section 4.8.6}

All provinces are expected to be highly exposed to projected decreases in ocean pH and aragonite saturation (Section 6.3). Decreases in the thickness of the skeletons and shells of some calcareous phytoplankton and zooplankton can be expected to occur, making them more susceptible to predation. However, effects in all provinces are likely to be limited because calcareous organisms comprise only a minor part of the food web (~ 5% of phytoplankton and zooplankton). Calcareous species adversely affected by ocean acidification are expected to be replaced by other species.

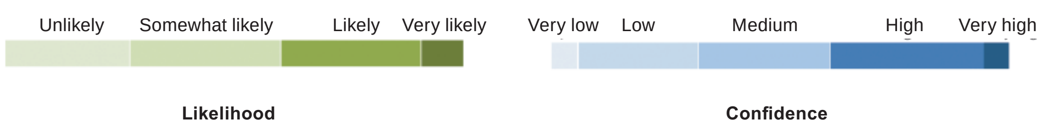
Overall vulnerability

The integrated vulnerability of food webs in each province under the B1 and A2 emissions scenarios in 2035 and 2100 is summarised in Table 6.3.

Table 6.3 Integrated vulnerability assessments for each of the five ecological provinces in the tropical Pacific Ocean for 2035 and 2100 for the B1 and A2 scenarios combined. Where ranges of values are provided for the projected changes, the lower and higher values represent the projections for B1 and A2, respectively. The likelihood and confidence values associated with these assessments are also shown.

Province	Year	Vulnerability	Projected changes
PEQD	2035	Moderate	Decrease in surface area of 20–27% as western boundary of PEQD moves eastwards from 180° to 170°W. Minor (2%) reduction in zooplankton biomass. No direct effect of higher SST, and lower O_2 and pH, on biomass or composition of plankton.
	2100	High	Decreases in surface area of 30–50% and movement of boundary to 160–150°W. A 2–4% increase in NPP and 3–6% decrease in biomass of zooplankton. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
Warm Pool	2035	Moderate	Increase in surface area eastwards by 18–21%, with a 5–7% reduction in NPP and 3–6% decrease in biomass of zooplankton throughout the water column. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
	2100	High	Increase in surface area eastwards by 26–48%, with a 9% reduction in NPP and 9–10% decrease in biomass of zooplankton throughout the water column. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
NPTG	2035	Low	Surface area increases limited to 1% as the province extends to the north. NPP decreases by 3–5% and zooplankton biomass declines by 3 to 4%. No direct effect of higher SST and O_2, or lower pH, on biomass or species composition of plankton.
	2100	Moderate	Increase in surface area stabilises at an increase of 1% but NPP decreases greatly (11–22%) and biomass of zooplankton declines by 10–18%. No direct effect of higher SST and O_2, or lower pH, on biomass or species composition of plankton.
SPSG	2035	Low	Surface area increases by 3–7%. NPP decreases by 4–5% and biomass of zooplankton declines by 3–4%. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
	2100	Low-Moderate	Surface area increases by 7–14% and extends poleward, with a 3–6% reduction in NPP and 5–10% decrease in biomass of zooplankton due to deepening of the thermocline. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
ARCH	2035	Low	No change in surface area. A reduction in NPP of 5–8% and a 5–6% decrease in biomass of zooplankton due to deepening of the thermocline. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
	2100	Moderate	No change in surface area. Greater (20–33%) reduction in NPP and a 17–26% decrease in biomass of zooplankton due to deepening of the thermocline. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.

SST = sea surface temperature; O_2 = dissolved oxygen percentage saturation at 300 m; PEQD = Pacific Equatorial Divergence; Warm Pool = Western Pacific Warm Pool; NPTG = North Pacific Tropical Gyre; SPSG = South Pacific Subtropical Gyre; ARCH = Archipelagic Deep Basins.



6.5 Vulnerability of coral reefs in the tropical Pacific to climate change {Chapter 5}[14]

Coral reefs are one of the most important coastal habitats in the tropical Pacific. Thousands of fish and invertebrate species are associated with the structures created by corals, many of which are important for the food security and livelihoods of Pacific Island people. Coral reefs support important fisheries for demersal fish, some nearshore pelagic fish, invertebrates targeted for export commodities, and invertebrates gleaned from shallow subtidal and intertidal areas for food {Chapter 9}. Maintaining the structural complexity of reef frameworks is vitally important to the continuation of these fisheries.

Under the B1 and A2 emissions scenarios in 2035 and 2100, coral reefs are projected to be vulnerable to increasing sea surface temperature (SST), ocean acidification, sea level, nutrient supply and cyclone intensity, as well as to changes to solar radiation, ocean circulation and upwelling. The vulnerability of coral reefs to the projected changes in these variables {Chapters 2 and 3}, in terms of their exposure and sensitivity, the potential impact of these changes, and their capacity to adapt, is summarised below.

Vulnerability of coral reefs to climate change

Sea surface temperature {Chapter 5, Section 5.6.1}

Coral reefs will be highly exposed and sensitive to the projected increases in SST {Chapter 3, Section 3.3.2}, with the symbiotic relationship between coral hosts and symbiotic dinoflagellates (*Symbiodinium*) breaking down under extended periods of thermal stress. The impact of thermal stress – known as coral bleaching – has been positively correlated with periods when SST exceeds the summer maxima by 1–2°C for 3–4 weeks or more, especially during strong El Niño events {Chapter 5, Section 5.5.1}. Varying thermal sensitivity of some coral genera is expected to lead to shifts in the species composition of corals on reefs as SST continues to increase. In particular, there is expected to be progressive dominance by heat-tolerant species. Certain corals appear to have the capacity to adapt to warmer waters by increasing the proportion of more temperature-tolerant *Symbiodinium* in their tissues. However, this strategy seems to provide added tolerance only up to increases of 1.5°C, and not extreme heat stress. This potential adaptive mechanism (called symbiont shuffling) also results in slower growth rates and potentially negative ecological implications. Therefore, it is unlikely to protect reefs from the severe and repeated damage projected to occur due to rapid warming of the tropical Pacific Ocean.

Solar radiation {Chapter 5, Section 5.6.2}

Coral reefs will be moderately exposed to changes in cloud cover associated with projected changes to the hydrological cycle {Chapter 2} and are sensitive to increases in photosynthetically active radiation (PAR) and ultraviolet radiation (UVR). Higher levels of PAR may exacerbate coral bleaching, whereas higher levels of UVR have the potential to increase damage to cellular components such as DNA. Corals have some ability to adapt to high and variable solar radiation through photoacclimation over a period of 5–10 days, although they remain physiologically stressed.

Ocean acidification {Chapter 5, Section 5.6.3}

Coral reefs will be highly exposed to the projected decreases in ocean pH {Chapter 3, Section 3.3.6}. Corals are expected to be highly sensitive to the reduced aragonite saturation levels that will result as more carbon dioxide (CO_2) dissolves in the sea {Chapter 3, Box 3.3} because they will be unable to build their skeletons at the same rate. The ability of corals and other marine calcifying organisms to maintain a positive reef carbonate balance is expected to fall into deficit when atmospheric concentrations of CO_2 exceed 450 ppm. Substantial decreases in calcification can be expected to result in more fragile and degraded reef frameworks. There is little evidence of calcifying organisms adapting to the lower concentrations of carbonate ions projected to occur under ocean acidification during the 21st century.

Cyclones and storms {Chapter 5, Section 5.6.4}

Coral reefs will be exposed to any increases in cyclone and storm intensity, and are highly sensitive to the local physical damage they cause, particularly in shallow reef environments. There are numerous examples of the physical impact of cyclones on coral reefs in the tropical Pacific, with full recovery taking 10–50 years. Coral communities regularly exposed to cyclones and storms are usually dominated by species with stout growth forms, and by fast-growing species, such as *Acropora* spp. However, these reefs have had thousands of years to adapt and no level of adaptation protects coral reefs from the severe damage caused by more intense (category 4 or 5) cyclones.

Rainfall patterns {Chapter 5, Section 5.6.4}

Coral reefs fringing high islands in the tropics will be highly exposed to the projected increases in rainfall {Chapter 2}. Corals are sensitive to the higher turbidity and nutrient enrichment, and lower salinity, associated with higher rainfall and floods. More intense rainfall is expected to deliver sediment and nutrient loads to coastal coral reefs, impeding photosynthesis of symbiotic dinoflagellates and creating more favourable conditions for the epiphytic algae that compete with corals. As a result, chronic impacts are expected on coral growth, recruitment and recovery after disturbances. Some corals can photoacclimate to lower light levels in turbid waters (with turbidity potentially protecting them from bleaching) and some species are more tolerant of higher sedimentation. However, these adaptations come at an energy cost and such corals may no longer form reefs of high complexity.

Sea level {Chapter 5, Section 5.6.5}

Coral reefs are expected to be exposed to the projected increases in sea level. Their sensitivity is expected to depend on the rate and magnitude of sea-level rise, as well as the influence of other factors on coral growth rate. In particular, reefs that are heavily stressed by increasing SST and ocean acidification are likely to be more sensitive to sea-level rise. It is difficult to be more specific about the response of coral reefs to rising sea level due to the uncertainty about the rate at which glaciers and ice caps will melt. Flows from melting land ice are an important determinant of sea-level rise {Chapter 3}, and the growth rate required by corals to keep pace with this rise.

Ocean circulation {Chapter 5, Section 5.6.6}

Coral reef ecosystems are expected to be exposed to changes in ocean circulation, upwelling and nutrient supply, and are highly sensitive to reductions in connectivity and net primary productivity. Changes in currents will have potential impacts on the replenishment rate of coral reef communities. Reductions in net primary production due to increased stratification {Chapters 3 and 4} are expected to cause disruptions to the ecology of both phototrophic species (e.g. corals and seaweed) and heterotrophic species (e.g. fish and invertebrates) associated with reefs. The relatively rapid projected rate of change in the availability of nutrients and the strength of currents means that many reef-associated species are unlikely to adapt.

Overall vulnerability

Ultimately, coral reefs are most vulnerable to increasing SST and ocean acidification (Table 6.4).

- Coral reefs have very high vulnerability to further increases in SST, and the projected increase in SST in the tropical Pacific region of 1–3°C by 2100 will influence the structure and function of coral reefs. Effects are expected to be clearly evident by 2035, with increasing frequency of mass coral bleaching events.
- The reduction in calcification rates at lower ocean pH suggests that corals, and the reefs they build, are highly vulnerable to ocean acidification. Increases in atmospheric CO_2 above 450 ppm are likely to result in net erosion of coral reefs throughout the tropical Pacific.
- On the basis of their capacity to photoacclimate within days, coral reefs appear to have a relatively low vulnerability to the projected changes in solar radiation.
- Coral reefs are expected to be moderately vulnerable to any increases in cyclone and storm intensity, and highly vulnerable to increases in rainfall and terrestrial inputs of sediments and nutrients due to more intense floods.
- The location of coral reefs will have a strong effect on the extent of their vulnerability to changes in ocean circulation – some reefs will receive fewer essential nutrients and recruits, whereas others will receive more.

- Coral reefs are likely to have low vulnerability to sea-level rise if the conservative projections from IPCC-AR4 {Chapter 3} are realised but will have moderate vulnerability if glaciers and ice caps melt rapidly as expected in more recent projections.

Table 6.4 Vulnerability of coral reefs to projected changes in surface climate and the ocean.

Sea surface temperature	Solar radiation	Ocean chemistry	Cyclones and storms	Rainfall patterns	Sea level*	Ocean circulation
Very high	Low	Very high	Moderate	High	Low-moderate	Moderate

* Range of vulnerability reflects the significant uncertainty regarding the rate of sea-level rise.

Projected changes in habitat area

Coral reef habitats are projected to change as emissions of greenhouse gases increase. Coral cover is expected to decline under both the B1 and A2 scenarios in the medium (2035) and long term (2100). Macroalgae (fleshy and turf algae) are projected to become more dominant (Figure 6.5).

Management of other human pressures on reefs, such as reduction of sediment and nutrient delivery from catchments, will assist reefs to tolerate increasing SST and ocean acidification and recover from disturbances. Strong management is expected to limit the loss of coral and proliferation of macroalgae under both scenarios in 2035, and B1 in 2100 but could have little effect under A2 in 2100 (Table 6.5).

Table 6.5 Estimated projected changes in the percentage cover of live coral and macroalgae on reefs in 2035 and 2100 for the B1 and A2 scenarios under poor and strong management, relative to 2010. The expected remaining cover (%) of coral and macroalgae (including feshy algae and algal turfs) is also shown. Likelihood and confdence associated with the projections are based mainly on the combined understanding of the expected responses of coral and macroalgae.

Year	Scenario	Management	Coral cover		Macroalgal cover	
			%	% decrease	%	% increase
2035	B1/A2	Strong	15–30	25–65	40	130
		Poor	15	65	40–60	130–200
2100	B1	Strong	10–20	50–75	50	> 150
		Poor	< 5	> 85	80	> 250
	A2	Strong	< 2	> 90	> 95	> 300
		Poor	< 2	> 90	> 95	> 300

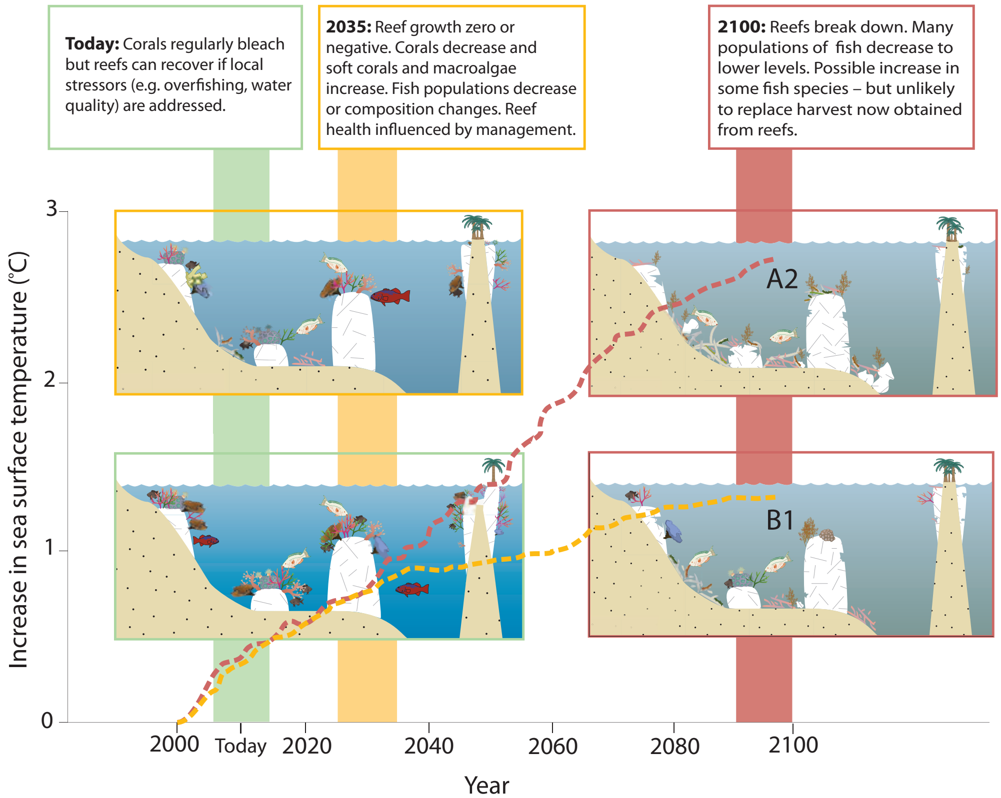


Figure 6.5 The future of coral reefs under B1 and A2 emissions scenarios. Note that the B1 and A2 trajectories are largely indistinguishable by 2035 but diverge after 2050. Under the B1 scenario in 2100, coral populations are projected to decrease and reefs are expected to be dominated by non reef-building species. Under the A2 scenario in 2100, sea surface temperatures and ocean acidity, as well as other factors such as turbidity and possibly cyclone intensity, are expected to increase. This is likely to lead to the complete loss of reef-building corals from reefs. Yellow and red vertical columns correspond to the range of years used to model the B1 and A2 emissions scenarios.

6.6 Vulnerability of mangroves, seagrasses and intertidal flats in the tropical Pacific to climate change {Chapter 6}[15]

The mosaic of mangroves, seagrasses, intertidal flats[i] and coral reefs along the coasts of Pacific Island countries and territories (PICTs) creates important fish habitats. Mangroves and seagrasses provide nursery areas for commonly harvested fish and invertebrates, and feeding grounds for many species of adult demersal fish targeted by coastal fisheries. Seagrasses and intertidal flats are permanent habitats for sea cucumbers – one of the main invertebrate export commodities from the region – and for a wide range of molluscs gleaned for subsistence {Chapter 9}. Maintaining these habitats is vitally important to the continuation of these fisheries.

Under the B1 and A2 emissions scenarios in 2035 and 2100, mangroves are projected to be vulnerable to sea-level rise, and possibly more intense cyclones. Seagrasses are expected to be vulnerable to increasing sea surface temperature (SST), variable solar radiation, changes to rainfall and possible increases in cyclone intensity. Intertidal flats are vulnerable to sea-level rise. The vulnerability of the plant species that create these habitats (including the algal mats of intertidal flats) to the projected changes in these variables {Chapters 2 and 3}, in terms of their exposure and sensitivity, the potential impact of these changes, and their capacity to adapt, is summarised below.

Vulnerability of coastal habitats to climate change

Temperature {Chapter 6, Sections 6.6.1.2 and 6.6.2.2}

Mangroves are expected to be highly exposed to increases in air and sea surface temperatures (SST). The trees are likely to be moderately sensitive to increases in SST because their respiratory demands will increase. Potential impacts for some mangrove species include development of more silt roots and smaller leaves, and greater mortality of young seedlings. Mangroves are able to adapt to higher air temperatures by reducing the apertures of their leaf stomata to cope with water loss induced by increased evaporation under heat stress. But mangroves have limited capacity to adapt to increasing SST.

Intertidal and subtidal seagrasses are also expected to be highly exposed to increases in air temperature and SST. These seagrasses are expected to be highly sensitive because chronic elevated SST increases respiratory demand that can exceed photosynthesis and affect their growth and survival. The potential impacts of increased SST include changes in species composition, relative abundance and distribution of seagrasses, as well as acute 'burn off' during short-term temperature spikes. The high light requirements of many tropical seagrass species and overall respiration demand will limit their ability to adapt to increasing SST by colonising deeper areas.

i Includes intertidal areas of sand and mud above mean low tide, but not intertidal coral reef or seagrass habitats.

Solar radiation {Chapter 6, Sections 6.6.1.1 and 6.6.2.1}

Mangroves are expected to be highly exposed to projected increases in solar radiation in subtropical areas. Mangroves are sensitive to increases in light but not to decreases. High levels of light, when coupled with lower rainfall, have the potential to overheat mangroves and damage cellular components such as DNA. Mangroves have limited ability to adapt to higher solar radiation.

Seagrasses are expected to be highly exposed to the projected reductions in solar radiation in the tropics. Seagrasses are sensitive to decreases in light, because the related declines in photosynthesis affect growth rates and eventually the species composition of seagrass communities. Where reduced light persists for long periods, the area of seagrass habitat decreases. High levels of UV light reduce production of chlorophyll in seagrass tissues and enhance production of pigments, causing 'reddening' of plant leaves. Seagrasses are able to respond to short-term reductions in light through a range of morphological and physiological adjustments.

Atmospheric carbon dioxide and ocean chemistry {Chapter 6, Sections 6.6.1.6 and 6.6.2.6}

Mangroves are expected to be exposed to projected increases in concentrations of atmospheric carbon dioxyde ($CO_{2)}$. Respiration and productivity of mangroves are likely to improve as atmospheric concentrations of CO_2 increase. A potential impact of higher atmospheric CO_2 concentrations is greater productivity of mangroves. Changes to the species composition of mangrove communities and encroachment into adjacent inland environments are likely to occur. Mangroves are also projected to be exposed to ocean acidification but are not expected to be sensitive.

Seagrasses are expected to be exposed to decreases in ocean pH but are unlikely to be sensitive because they currently experience greater variations in pH on a daily basis. Seagrass may in fact benefit from increasing CO_2 concentration through increased productivity, biomass and reproductive output as a result of faster photosynthetic rates. This could allow some species of seagrass to colonise areas with lower light, such as deeper water.

Cyclones and storms {Chapter 6, Sections 6.6.1.5 and 6.6.2.5}

Mangroves are likely to be exposed to any increases in cyclone and storm intensity, and are highly sensitive because cyclones damage foliage, desiccate plant tissues, and increase evaporation rates and salinity stress. More powerful wave surge during cyclones erodes sediments on the seaward edge of mangroves and reduces the stability of plants. Mangrove species have different tolerances to cyclone damage – some species can resprout from dormant buds. Over time, recruitment of mangrove seedlings occurs from adjacent undamaged areas.

Seagrasses in intertidal and shallow subtidal areas will also be exposed to any increases in cyclone and storm intensity, and are particularly sensitive to the physical effects of storm surge and increased turbidity associated with cyclones. Severe storms can impact seagrass habitats through the combined effects of physical disturbance (stripping leaves and uprooting plants), reductions in light (reducing photosynthesis) and salinity, and movement of sediments (smothering plants). Small species of seagrass suffer more damage from cyclones than larger species which have rhizomes buried deeper in the sediment. However, smaller species have the capacity to recover rapidly provided propagules are available from nearby meadows.

Rainfall patterns {Chapter 6, Sections 6.6.1.3 and 6.6.2.3}

Mangroves are expected to be highly exposed to projected changes in rainfall and are moderately sensitive to the resultant changes in soil salinity, freshwater saturation and sediment delivery. Increased rainfall will lower salinity, which may benefit mangroves but will also increase soil inundation by freshwater, potentially affecting root growth, especially in seedlings. Decreased rainfall has the potential to cause more significant impacts, by increasing soil salinity to the point where it affects plant growth, reducing sediment delivery for vertical accretion, and reducing flowering and fruiting. Mangroves can adapt to decreasing rainfall by using water more efficiently and reducing transpiration rates to avoid water loss.

Seagrasses are expected to be highly exposed to increases in rainfall in the tropics. Seagrasses are moderately sensitive to the associated changes in turbidity, sedimentation, delivery of nutrients and pollutants, salinity and physical scouring. Seagrasses have low adaptive capacity to high levels of turbidity, sediment deposition, pollution and scouring. However, some species are more tolerant of low salinity and such species would be expected to become more prevalent.

Sea level {Chapter 6, Sections 6.6.1.7 and 6.6.2.7}

Mangroves are expected to be highly exposed to projected rises in sea level. In particular, mangroves are expected to be inundated by sea water more frequently, and to be inundated permanently in low-lying areas. The sensitivity of mangroves is expected to be high to very high depending on the rate and magnitude of sea-level rise. More frequent inundation by sea water has critical implications for plant growth, respiration and survival. The ability of mangroves to migrate landward as sea level rises is an important adaptation, but will depend on (1) topography, (2) the rate of sea-level rise, (3) hydrology, (4) sediment composition, and (5) competition with non-mangrove species in landward areas. There is concern that the capacity of mangroves to migrate landward may not be able to keep pace with the projected accelerated rate of sea-level rise. In many places, steep terrain and existing infrastructure (e.g. roads) will prevent any migration.

Seagrasses are also expected to be exposed to projected sea-level rise and are likely to be sensitive because increasing depth reduces the light available to deeper plants, limiting photosynthesis and growth. The potential impacts are expected to be losses in seagrass area or changes in species composition in deeper meadows. Seagrasses growing along the deeper margins of meadows are at the limit of their light tolerance and are unlikely to be able to adapt to further light reductions. However, seagrasses in some intertidal and shallow subtidal areas can adapt to rising sea levels by growing landward, provided the newly inundated sediments are suitable.

Intertidal flats and the productive benthic microalgae communities that they support are expected to be highly exposed to sea-level rise. Intertidal flats are likely to be highly sensitive to rising sea levels where there is little scope for expansion landward due to barriers. The potential impacts of sea-level rise include considerable losses of intertidal habitat, and the associated species that are not adapted to live subtidally.

Nutrient delivery {Chapter 6, Sections 6.6.1.4 and 6.6.2.4}

Mangroves are expected to be exposed and sensitive to projected changes in nutrient levels associated with more variable rainfall patterns. In general, increased nutrients may fertilise mangroves and increase their growth. The additional sediments usually associated with higher levels of runoff can also assist mangroves to adapt to rising sea levels through enhancement of vertical accretion. But reductions in nutrient delivery due to low rainfall also have the potential to affect plant growth and the species composition of mangrove communities. The potential beneficial impacts of increases to nutrients will be most evident when coupled with increases in air temperature and CO_2. Adaptations of mangroves to changes in nutrient levels are expected to be most evident at the community level, with different species dominating under particular nutrient conditions.

Seagrasses are expected to be exposed to projected changes in nutrient delivery and will be moderately sensitive. Increases in nutrients up to a certain level in the water column are expected to enhance seagrass growth. However, excessive nutrient concentrations promote the growth of epiphytes on seagrass leaves, blocking light and retarding seagrass growth. On balance, the potential impacts are likely to be generally beneficial but seagrasses have little capacity to adapt to heavy growth of epiphytes.

Overall vulnerability

Mangroves are projected to be most vulnerable to sea-level rise, changes to rainfall and any increase in cyclone and storm intensity. Mangroves are expected to have an overall moderate vulnerability to climate change in 2035 under both scenarios, increasing to high under B1 in 2100, and very high under A2 in 2100 (Table 6.6).

Seagrasses are projected to be most vulnerable to increasing SST, decreasing light, changing rainfall patterns and any increases in cyclone and storm intensity. Seagrasses are expected to have an overall moderate vulnerability under both scenarios in 2035 and B1 in 2100, increasing to high under A2 in 2100 (Table 6.6).

Intertidal flats are projected to be most vulnerable to sea-level rise, and are expected to have low vulnerability under the B1 and A2 emissions scenarios in 2035, increasing to high in 2100.

Table 6.6 Summary of vulnerability of mangroves and seagrasses to projected changes in surface climate and the ocean.

	SST	Solar radiation	Ocean chemistry	Cyclones and storms	Rainfall patterns	Sea level	Nutrients
Mangroves							
B1/A2 2035	Very low	Low	Very low	Moderate	Low	High	Low
B1 2100*	Very low	Low	Very low	Moderate	Moderate	Very high	Low
A2 2100	Very low	Low	Very low	Moderate	Moderate	Very high	Low
Seagrasses							
B1/A2 2035	Moderate	Moderate	Very low	Moderate	Moderate	Low	Low
B1 2100*	Moderate	Moderate	Very low	Moderate	Moderate	Moderate	Low
A2 2100	High	High	Very low	High	High	Moderate	Moderate

* Approximates A2 in 2050; SST = sea surface temperature.

Projected changes in habitat area

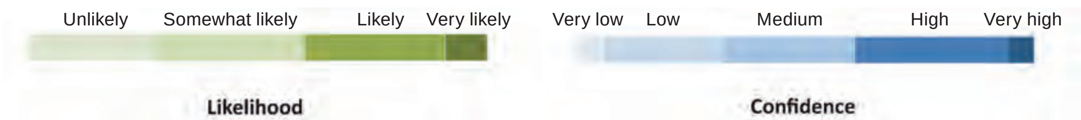
Ultimately, the vulnerability of mangroves to sea-level rise, changes in rainfall and possible increases in cyclone intensity, is projected to reduce the areas of mangrove habitat in Pacific Island countries and territories, with the declines becoming greater over time.

The vulnerability of seagrasses to increasing SST, decreasing solar radiation, changing rainfall patterns and possible increases in cyclone intensity is projected to reduce seagrass area, with declines expected under both the B1 and A2 scenarios in the short term (2035) and long term (2100) (Table 6.7).

The area of intertidal flats is also expected to decrease. However, it is not possible to estimate the area likely to be lost due to poor baseline data for this habitat in the region.

Table 6.7 Projected loss of mangrove and seagrass habitat under B1 and A2 emissions scenarios in 2035 and 2100, relative to 2010.

Year	Scenario	Mangrove area (%)	Seagrass area (%)
2035	B1/A2	-10 to -30	< -5 to -20
2100	B1	-50 to -70	-5 to -35
2100	A2	-60 to -80	-10 to -50



6.7 Vulnerability of freshwater and estuarine habitats in the tropical Pacific to climate change {Chapter 7}[16]

Freshwater and estuarine habitats occur mainly in the western Pacific, where rivers and lakes support a diversity of fish and invertebrates {Chapter 10}. The extent of some of these habitats is significant - the Sepik-Ramu, Fly and Purari rivers in Papua New Guinea (PNG) have annual discharges among the highest in the world. On the other hand, many rivers in other Pacific Island countries and territories are too small to maintain permanent freshwater flows. Nevertheless, throughout much of the region, freshwater and estuarine fish and invertebrates contribute to food security {Chapter 10}.

Under the B1 and A2 emissions scenarios in 2035 and 2100, freshwater and estuarine habitats in the subtropical Pacific are projected to be vulnerable to decreases in rainfall, sea-level rise, increasing temperature and possibly increasing cyclone intensity. However, freshwater habitats in equatorial regions may benefit from increasing rainfall and air temperatures. The vulnerability of these habitats to the projected changes in surface climate and the ocean {Chapters 2 and 3}, in terms of their exposure and sensitivity, the potential impact of these changes, and their capacity to adapt, is summarised below.

Vulnerability of freshwater and estuarine habitats

Temperature {Chapter 7, Sections 7.5.4 and 7.6.2}

Freshwater and estuarine habitats are expected to be exposed to projected increases in temperature. Shallow, low-flow environments, such as high-elevation lakes, river edges and floodplain wetlands, are expected to be sensitive to these changes because warmer air temperatures will increase evaporation and water temperatures. The limited mixing in shallow freshwater floodplain and edge environments is likely to result in water temperatures that exceed the tolerance of many fish and invertebrates, particularly those living in coldwater lakes. The macrophyte species that create fish habitats in environments such as intertidal estuaries, that already experience daily temperature fluctuations of up to 10°C, are likely to be able to adapt. However, some macrophytes in other habitats may have limited capacity to adapt to increasing water temperatures.

Cyclones and storms {Chapter 7, Sections 7.5.2 and 7.6.2}

Freshwater habitats in coastal areas and estuaries may be exposed to more severe cyclones and storms. The vegetation that creates many freshwater and estuarine fish habitats is sensitive to damage by floods associated with cyclones. Floods can also change riverine landscapes. Potential impacts include creation of new channels, transport of coarse sediments, floodplain sedimentation, the collapse of river banks and scouring of river beds. However, freshwater river habitats are dynamic systems that change and reform in response to floods, provided the capacity for river beds to expand and contract is not constrained. Storm surge is also expected to cause saline intrusion in floodplain and freshwater environments, and higher saltwater penetration in coastal plain estuaries and tidal rivers. The vegetated components of freshwater fish habitats have limited capacity to adapt to increasing salinity or extended inundation by salt water.

Rainfall patterns {Chapter 7, Sections 7.5.1 and 7.6.2}

Freshwater and estuarine habitats are expected to be highly exposed to projected changes in rainfall and to be sensitive to both increases and deceases in rainfall. Higher rainfall will lead to greater flows and flooding, which will improve connectivity between the mosaic of habitats but also increase erosion and sedimentation. On balance, freshwater habitats in the tropics are expected to benefit from the projected increases in rainfall. However, in the subtropics, the decreases in rainfall are expected to reduce flows and connectivity. In floodplain habitats, the vegetation that helps create many fish habitats is likely to have much potential to adapt to increases in the frequency and duration of inundation.

Sea level {Chapter 7, Sections 7.5.5 and 7.6.2}

Freshwater habitats in low-lying areas and estuaries are expected to be highly exposed to inundation by sea water due to projected sea-level rise. The plants in these habitats will be sensitive to the changes in salinity. In particular, mangroves and salt marsh vegetation are expected to move landward and freshwater vegetation with little tolerance to increases in salinity is expected to disappear. However, if the rate of sea-level rise is rapid, the ability of mangroves to colonise new areas will be compromised {Chapter 6}. Where the upstream extent of estuaries is not constrained, estuarine habitats are expected to migrate landward. However, estuaries that are unable to retreat because of steep topography or other barriers are likely to be reduced in area.

Overall vulnerability

Freshwater habitats in equatorial areas are expected to benefit from increasing rainfall that will enhance river flows and result in better growth of aquatic vegetation at higher temperatures. In the subtropics, freshwater habitats are expected to be vulnerable to the projected decreases in rainfall, particularly in shallow low-flow environments. Estuaries and low-lying freshwater habitats close to the coast are likely to have high vulnerability to sea-level rise, and any increase in cyclone intensity, under both scenarios in 2035 and 2100 (Table 6.8).

Table 6.8 Vulnerability of freshwater and estuarine habitats to projected changes in surface climate in 2035 and 2100, relative to 2010.

	Temperature	Cyclones and storms[a]	Rainfall	Sea level[a]
Equatorial				
B1/A2 2035	Low	Low/High	Low	Low/High
B1 2100*	Low	Low/High	Low	Low/High
A2 2100	Low	Low/High	Low	Low/High
Subtropical				
B1/A2 2035	Low	Low/High	Moderate	Low/High
B1 2100*	Moderate	Low/High	High	Low/High
A2 2100	High	Low/High	High	Low/High

* Approximates A2 in 2050; a = vulnerability reflects the different locations of habitats with coastal and low-lying freshwater and estuarine habitats having high vulnerability to more intense cyclones and sea-level rise, whereas inland areas are expected to have a low vulnerability.

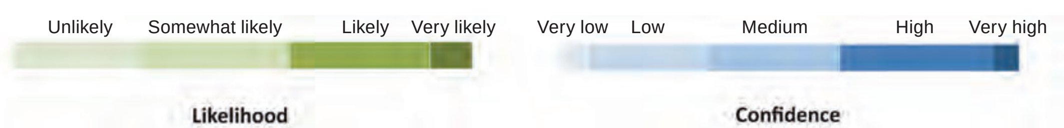
Projected changes in habitat area

Ultimately, the projected effects of climate change are expected to increase the area of freshwater habitats in equatorial regions and reduce the area of these habitats in the subtropics (Table 6.9).

Maintaining riparian vegetation to shade rivers and control water temperature, and minimising the loss of catchment vegetation to reduce delivery of sediments and nutrients to rivers, will assist freshwater and estuarine habitats to cope with projected changes to the climate. These management measures should also facilitate increases in habitat area where conditions are suitable.

Table 6.9 Projected change in freshwater habitat (%) under B1 and A2 emissions scenarios in 2035 and 2100, relative to 2010.

Year	Scenario	Freshwater area (%)
2035	B1/A2	-5 to +10
2100	B1	-10 to +20
2100	A2	-20 to + > 20



6.8 Vulnerability of oceanic fisheries in the tropical Pacific to climate change {Chapter 8}[17]

Oceanic fisheries are of vital importance to the economies and people of Pacific Island countires and territories. These fisheries are dominated by skipjack, yellowfin, bigeye and albacore tuna, with recent total catches from the Western and Central Pacific Ocean (WCPO) for all species combined approximating 2.5 million tonnes per year. The catch from the WCPO provided 58% of the estimated global tuna catch in 2009 and the catch from the EEZs of Pacific Island countries and territories made up 48% of the catch from the WCPO. The distributions and abundances of the four tuna species, and other pelagic fish, are influenced greatly by oceanic conditions. Changes in currents, ocean temperature, dissolved oxygen and the nature of the five ecological provinces in the WCPO {Chapter 4} are expected to affect the catches of tuna.

Under the B1 and A2 emissions scenarios in 2035 and 2100, tuna are expected to be exposed directly to changes in ocean temperature, currents and ocean chemistry, and dissolved oxygen. Tuna are also likely to be exposed to changes in the food webs on which they depend. However, due to the high mobility of adult tuna, these changes are not expected to result in significant vulnerability of oceanic fisheries. Rather, they are expected to cause shifts in distribution of tuna to the east and changes in the 'catchability' of tuna. The vulnerability of tuna species to the projected changes in the main physical, chemical and biological features of the tropical Pacific Ocean {Chapters 3 and 4}, in terms of their exposure and sensitivity, the potential impact of these changes, and their capacity to adapt, is summarised below.

Vulnerability of tuna to the direct effects of climate change

Ocean temperature {Chapter 8, Section 8.4.1}

The four main species of tuna in the tropical Pacific are expected to be highly exposed to projected increases in surface and sub-surface temperature. These species are also expected to be sensitive to changes in temperature because it regulates metabolism and development, and limits activity and distribution. Tuna are most sensitive to changes in temperature during their larval and juvenile life stages but have wider temperature tolerances as they mature. Projected ocean warming may affect the distribution of tuna by changing spawning locations and success, and accessibility to feeding areas due to increased stratification of the water column. However, the four tuna species are expected to adapt fairly easily to the changing conditions in the ocean. Both juvenile and adult tuna are highly mobile and can follow their preferred temperature range and prey, as presently observed during the different phases of the El Niño-Southern Oscillation.

Ocean chemistry {Chapter 8, Section 8.4.4}

Tuna species will be exposed to projected ocean acidification and are expected to be sensitive because ocean chemistry affects blood pH, otolith formation and ocean acoustics. Most fish tolerate a wide range of dissolved CO_2 concentrations and pH, but there are likely to be potential physiological impacts associated with compensating for acidosis (lower blood pH), such as lower growth rates and egg production. Other potential impacts include reduced otolith formation (because otoliths are made of aragonite), and impaired acoustic ability of tuna to assess their physical and biological environment, and detect prey and predator species. Acidosis could also lead to a narrowing of the optimal thermal performance range and, consequently, altered resistance, metabolic rate and behaviour of tuna. Ocean acidification could also affect the behaviour of tuna larvae, reducing survival. The capacity of tuna to adapt to ocean acidification is unknown.

Ocean circulation {Chapter 8, Section 8.4.3}

Tuna are expected to be exposed to changes in ocean circulation and are likely to be sensitive to such changes because currents (and SST) determine the location of spawning grounds, the dispersal of larvae and juveniles, and the distribution of prey. Potential impacts include changes in the location of spawning grounds eastward or to higher latitudes, altered retention of larvae in areas favourable for growth and survival, and shifts in the distribution of prey for juveniles and adults to the east {Chapter 4}. Tuna are expected to have considerable capacity to adapt their behaviour to seek out suitable conditions for spawning and productive feeding areas. Such alterations in behaviour are likely to result in changes in distribution to the east and to higher latitudes.

Dissolved oxygen {Chapter 8, Section 8.4.2}

Tuna will be highly exposed to possible reductions in dissolved oxygen (O_2), and are expected to be sensitive to these changes because O_2 is critical for maintaining metabolic rate and mobility. Sensitivity to the availability of dissolved oxygen and to lethally low levels of O_2 vary among tuna species. Skipjack tuna and albacore tuna are less tolerant to low oxygen concentrations than yellowfin tuna. Bigeye tuna are the most tolerant species. Changes in O_2 in subsurface waters are expected to have limited impact on skipjack tuna, which inhabit the surface layer. However, greater impacts are possible for tuna species that swim regularly between the surface and subsurface (yellowfin tuna and albacore) and to deeper layers (bigeye tuna). Any decrease in O_2 concentrations at mid to high latitudes may limit the extension of tuna habitat into more temperate areas. Tuna can adapt to reductions in dissolved oxygen by changing the ocean layers they use, with subsurface areas expected to be used more in the northern than in the southern Pacific, due to marked differences in projected O_2 levels. Changes in the concentration of dissolved oxygen are expected to have effects on the distribution and catchability of tuna.

Vulnerability of oceanic fisheries to the indirect effects of climate change

Changes to food webs {Chapter 8, Sections 8.5.1 and 8.5.2}

Tuna are eventually expected to be exposed to declines in primary productivity in much of the tropical Pacific Ocean due to increased stratification of the water column {Chapter 3}. The reduced supply of nutrients is likely to change the composition of food webs for tuna {Chapter 4}. Tuna are expected to be particularly sensitive to any decrease in the productivity of the micronekton they feed on because of their high energy requirements for rapid growth, great rates of egg production, and constant and fast swimming activity. Any mismatches between periods of high primary productivity and spawning events, and between the distribution of larvae and their zooplanktonic food, are expected to affect the survival of larvae and subsequent recruitment success of tuna. A projected shift of the convergence between the Warm Pool and Pacific Equatorial Divergence Province {Chapter 4} to the east would change the location of the best feeding grounds for skipjack tuna. The projected reductions in the productivity of food webs in the Warm Pool and the subtropical gyres (Section 6.4) are likely to result in lower catches of tuna in these provinces. The highly mobile nature of tuna is expected to assist them to adapt to changes in the availability of micronekton prey by moving to more favourable feeding grounds.

Overall vulnerability

The skipjack tuna that underpin much of the catch by oceanic fisheries in the tropical Pacific are projected to be most vulnerable to increasing ocean temperatures, lower primary productivity and to a lesser extent reduced dissolved oxygen (Table 6.10). The greatest effects on skipjack tuna are projected to be distributional shifts eastward and to higher latitudes, primarily as a result of (1) increasing ocean temperature making the western equatorial Pacific unsuitable for spawning; and (2) the contraction of the productive convergence zone between the Warm Pool and the Pacific Equatorial Divergence Province to the east.

Table 6.10 Vulnerability of adult skipjack and bigeye tuna to projected changes in the tropical Pacific Ocean

	Ocean temperature	Ocean chemistry	Ocean circulation*	Dissolved oxygen	Primary productivity (mid trophic)**
Skipjack					
B1/A2 2035	Low	Low	Low	Low	Medium
B1 2100*	Medium	Low	Low	Low	High
A2 2100	High	Medium	Medium	Medium	High
Bigeye					
B1/A2 2035	Low	Low	Low	Low	Low
B1 2100*	Medium	Low	Low	Medium	Medium
A2 2100	High	Medium	Medium	High	High

* Approximates A2 in 2050; ** larvae will be more vulnerable than the more mobile adults.

Projected changes in oceanic fisheries

Preliminary modelling indicates that catches of skipjack tuna are likely to increase across the region in 2035, although the increases are expected to be greater for PICTs in the eastern Pacific than in the western Pacific. By 2100 under the B1 scenario (A2 in 2050), catches for the western Pacific are projected to decrease and return to the average levels for the region in 1980–2000. In contrast, average catches in the eastern Pacific are expected to increase by > 40% (Table 6.11).

Under the A2 scenario in 2100, average catches of skipjack tuna for the western Pacific are estimated to decline by > 20%. Although catches in the eastern Pacific are still projected to be substantially greater compared to 1980–2000 levels, they are expected to decrease relative to the projections for the B1 scenario. Across the entire region, total catch is projected to decrease by 7.5% under the A2 scenario by 2100 (Table 6.11).

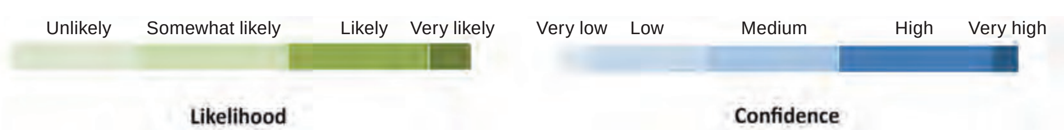
For bigeye tuna, small decreases in catch (usually < 5%) are projected to occur across much of the region by 2035. The magnitude of the reduced catches is projected to increase to 5–10% under the B1 scenario by 2100, and 10–30% for many PICTs under the A2 scenario in 2100 (Table 6.11).

Modelling for yellowfin tuna and albacore is now in progress.

Table 6.11 Projected percentage changes in average catches of skipjack and bigeye tuna for the eastern and western Pacific, in 2035 and 2100 under the B1 and A2 emissions scenarios relative to 1980–2000 levels (note that results are based on preliminary modelling only).

	West[a]			East[b]		
	B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
Skipjack tuna	+10	0	-20	+30 to 35	+40 to 45	+25 to 30
Bigeye tuna	0 to -5	-10 to -15	-30 to -35	0 to +5	0 to -5	-15 to -20

* Approximates A2 in 2050; a = 15°N–20°S and 130°–170°E; b = 15°N–15°S and 170°E–150°W.



6.9 Vulnerability of coastal fisheries in the tropical Pacific to climate change {Chapter 9}[18]

Coastal fisheries contribute significantly to the food security, livelihoods, and culture of Pacific Island people – fish consumption per person across much of the region is at least 2–4 times higher than the global average. The wide variety of species caught by coastal fisheries can be separated into demersal fish (bottom-dwelling fish associated with coral reef, mangrove and seagrass habitats), nearshore pelagic fish, invertebrates targeted for export and invertebrates gleaned from subtidal and intertidal habitats. The total contribution of subsistence and commercial coastal fisheries to national gross domestic product (GDP) across the region is estimated to be USD 272 million, with > 70% of the total catch being taken by subsistence fishing.

Under the B1 and A2 emissions scenarios in 2035 and 2100, the fish and invertebrate species that comprise coastal fisheries are projected to be directly exposed to increasing sea surface temperature (SST), ocean acidification, and changes to ocean circulation. These species are also expected to be indirectly exposed to climate change through alterations to their supporting habitats. The vulnerability of coastal fisheries species to the projected changes in these variables {Chapters 3, 5 and 6}, in terms of their exposure and sensitivity, the potential impact of these changes, and their capacity to adapt, is summarised below.

Vulnerability of coastal fish and invertebrates to the direct effects of climate change

Sea surface temperature {Chapter 9, Section 9.3.1.1}

Coastal fisheries species are expected to be highly exposed to projected increases in SST, and are likely to be sensitive to these changes because temperature regulates metabolism and development, and influences activity and distribution. Many coastal fish and invertebrate species experience a range of temperatures each day, and during different seasons. As a result, such species are relatively tolerant of short-term changes in temperature. However, all species have a thermal optimum and when this threshold is exceeded, increased metabolic rate and oxygen demand may interfere with reproduction, recruitment and growth of juvenile and adult fish. Many species may be able to adapt through settlement of larvae in places outside the normal distributional range of the species where temperatures remain below the thermal optimum threshold. Such adaptation will be difficult for species that depend on coral reefs, if there are no reefs available within the relocated optimal temperature range.

Ocean acidification {Chapter 9, Section 9.3.1.2}

Coastal fisheries species are expected to be exposed to ocean acidification which is projected to result in decreases in aragonite saturation state {Chapter 3}. Invertebrates are sensitive to decreases in aragonite saturation states below the threshold levels needed for them to build shells of normal thickness – predation is expected to be greater on molluscs with thinner shells. The sensory ability of larval and postlarval demersal fish can also be impaired by acidification of the ocean, leading to a loss of their ability to navigate to reefs, distinguish beneficial settlement sites and detect and avoid predators. The adaptive capacity of coastal fisheries species to ocean acidification is expected to be low because ocean pH has changed very little over the past 800,000 years. Consequently, marine organisms are likely to lack the genetic variation necessary for rapid adaptation to changes in seawater chemistry.

Ocean circulation {Chapter 9, Section 9.3.1.3}

The pelagic larval stages of coastal fish and invertebrates are expected to be exposed to changes in ocean circulation particularly in areas under the influence of the South Equatorial Current and South Equatorial Counter Current {Chapter 3}. Resident adults on coral reefs and in other coastal habitats are also likely to be exposed to changes in the strength and persistence of upwellings and associated delivery of nutrients from deepwater. Fisheries species can be expected to be sensitive to the reduced opportunities for larval dispersal and nutrition resulting from this exposure. Potential impacts include changes in the supply of postlarvae to replenish resident populations, resulting in a general decline in productivity of coastal fisheries. The composition of demersal fish communities can be expected to change in favour of species with good potential for local self-replenishment.

Other variables

Coastal fisheries species are projected to have low vulnerability to sea-level rise, changes to rainfall and solar radiation, and possible increases in cyclone and storm intensity. These variables are expected to have the most influence on fish and invertebrate species, indirectly, through their effect on coastal habitats (see below).

Vulnerability of coastal fish and invertebrates to the indirect effects of climate change

Habitat degradation {Chapter 9, Section 9.3.2}

Coastal fish and invertebrate species are expected to be indirectly exposed to climate change through the projected changes to the coral reef, mangrove, seagrass and intertidal flat habitats {Chapters 5 and 6} on which they depend. Coastal fisheries species are likely to be highly sensitive to changes to the habitats that provide them with food and shelter. The potential impacts include reduced diversity and abundance of fish and invertebrates as food resources decline, and increased rates of mortality (predation) as structurally complex habitat (shelter) is lost. Specialist species that depend directly on live coral for food and shelter are likely to experience greater impacts than generalists, which can switch to using alternative resources. Generalist species such as the carnivorous snappers and emperors are expected to adapt because they already use a range of habitats. Significant changes in species composition of demersal fish associated with coral are expected. In particular, the proportions of herbivores (parrotfish, surgeonfish, rabbitfish) are likely to increase as the percentage cover of live corals declines and the cover of macroalgae (seaweed) increases.

Overall vulnerability

Coastal fisheries species are projected to be most vulnerable to increasing SST, ocean acidification, changes to ocean circulation and habitat degradation. The demersal fish which are estimated to make up 50–60% of coastal fisheries production across the region are expected to have a low vulnerability to the combined effects of the projected increases in SST, ocean acidification, changes in currents and alterations to habitats in 2035. However, their vulnerability is expected to increase to moderate in 2100 under the B1 emissions scenario, and to high under the A2 scenario.

The vulnerability of the nearshore pelagic fish, which comprise ~ 30% of the coastal fisheries catch, is likely to differ across the region due to the different contributions of tuna to this catch in the east and the west, and the projected shift in distribution of skipjack and yellowfin tuna to the east {Chapter 8}. In the west, nearshore pelagic fish are expected to have little or no vulnerability to climate change in 2035, increasing to low to moderate in 2100 under the B1 scenario and to moderate under A2. In the east, the net effect of climate change on nearshore pelagic fish is expected to be positive under all scenarios.

Targeted invertebrates are estimated to have a low vulnerability to climate change in 2035, increasing to moderate under the B1 scenario, and to high under the A2 scenario, in 2100. The suite of invertebrates gleaned from intertidal and subtidal habitats are estimated to have little or no vulnerability to climate change in 2035, increasing to low to moderate under the B1, and to moderate under A2, in 2100.

Projected changes in fisheries productivity

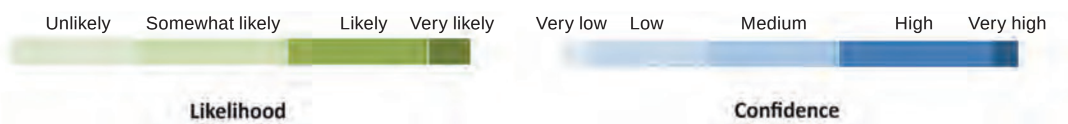
Overall, the production of demersal fish is estimated to decrease by < 5% in 2035 due to the effects of climate change. However, production of demersal fish is expected to be reduced by 20% under the B1 scenario in 2100 (A2 in 2050), and by 20–50% under A2 in 2100. Although demersal fish dominate the production of coastal fisheries, the overall decreases in total coastal fisheries production are tempered by the projected changes to catches of nearshore pelagic fish, which consist of a high proportion of tuna in many PICTs. Decreases in productivity of the two invertebrate groups are also expected to be lower than for demersal fish.

When the different projected changes in production of the four components of coastal fisheries due to climate change are combined, negligible reductions in total coastal fisheries catch are expected by 2035 in both the western and eastern parts of the region (Table 6.12). By 2100 in the west, a decrease in total production of 10–20% is expected under the B1 scenario (A2 in 2050), and a decrease of 20–35% is projected under A2. Due the expected shift in distribution of tuna, the decreases in total coastal fisheries production in the east are expected to be limited to 5–10% under B1 in 2100 (A2 in 2050) and 10–30% under A2 in 2100.

Table 6.12 Vulnerability (V) and projected changes in production (P) of the four categories of coastal fisheries and total coastal fisheries production in 2035 and 2100 for the B1 and A2 emissions scenarios. Note that the availability of nearshore pelagic fish is expected to increase in the eastern part of the region {Chapter 8}. The main potential impacts of climate change projected to cause future variations in production of coastal fisheries are also summarised here.

Variable			Coastal fisheries category					Total coastal fisheries***	
			Demersal fish	Nearshore pelagic fish		Targeted invertebrates	Shallow subtidal and intertidal invertebrates		
Present contribution to coastal fisheries production			56%	28%		2%	14%		
				West*	East**			West*	East**
Vulnera-bility and projected change in production	B1/A2 2035	**V**	L	nil	L	L	nil[a]	nil[a]	nil[a]
		P	-2 to -5%	nil	+15 to +20%	-2 to -5%	nil	Negligible	Negligible
	B1 2100	**V**	M	L-M	L	L-M	L	M	L
		P	-20%	-10%	+20%	-10%	-5%	-10 to -20%	-5 to -10%
	A2 2100	**V**	H	M	L	M	L-M	M-H	M
		P	-20 to -50%	-15 to -20%	+10%	-20%	-10%	-20 to -35%	-10 to -30%
Major impacts			Habitat loss, and reduced recruitment due to ⇧SST and ⇩currents	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna		Habitat degradation, and declines in aragonite saturation due to ocean acidification	Declines in aragonite saturation due to ocean acidification		

* 15°N–20°S and 130°–170°E; ** 15°N–15°S and 170°E–150°W; *** assumes that the proportions of the four coastal fisheries categories remain constant; a = nil or very low vulnerability; ⇧ = increasing sea surface temperature; ⇩ = reduced currents; L = low; M = moderate; H = high.



6.10 Vulnerability of freshwater and estuarine fisheries in the tropical Pacific to climate change {Chapter 10}[19]

Freshwater and estuarine fisheries in the tropical Pacific provide ~ 24,000 tonnes of fish and invertebrates per year and contribute 4% of the regional contributions to GDP derived from fisheries. Most of this production comes from Papua New Guinea (PNG), although significant harvests are also made in Fiji and Solomon Islands. Freshwater and estuarine fish form an important part of the diet for people in some inland areas in PNG. For example, communities living along parts of the Fly River in PNG consume up to 2 kg of fish per person per week. Alterations in freshwater and estuarine fish production as a result of climate change have the potential to affect the food security and livelihoods of people in inland areas of the region.

Under the B1 and A2 emissions scenarios in 2035 and 2100, freshwater and estuarine fish and invertebrate species are projected to be directly exposed to increasing water temperature and changes in river flows, salinity, dissolved oxygen and turbidity. These species are also expected to be indirectly vulnerable to climate change through alteration to the habitats that support them {Chapter 7}. The vulnerability of these species to the projected changes in surface climate {Chapter 2}, river flow and fish habitats {Chapter 7}, in terms of their exposure and sensitivity, the potential impact of these changes, and their capacity to adapt, is summarised below.

Vulnerability of freshwater and estuarine fisheries to the direct effects of climate change

Water temperature {Chapter 10, Section 10.3.1}

Freshwater and estuarine fish and invertebrates are expected to be exposed to projected increases in water temperature of 0.5–1.0°C in 2035, up to 1.5°C under the B1 emissions scenario in 2100 (A2 in 2050) and up to 3.0°C under A2 in 2100. Clearing of catchment vegetation may also increase the warming of aquatic habitats. Depending on their distribution within river systems, some fish and invertebrate species are expected to be sensitive to these changes. Species inhabiting shallow low-flow environments, such as high-elevation lakes, river edges and floodplain wetlands, are expected to have the greatest sensitivity to warmer temperatures. Increasing water temperatures are likely to have potential impacts on larval fish growth, muscle fibre development, swimming ability, metabolic rate and sex ratios. However, not all the expected effects are negative – some freshwater fish and invertebrate species are likely to benefit. In particular, the distributions of species currently limited by their lower temperature tolerances are expected to expand as waters warm. Growth rates are also estimated to increase where temperatures remain within the ranges tolerated by species. However, where increases in temperature are coupled with contaminants from mining, forestry and intensive agriculture operations, the temperature tolerances of species could decrease by more than 4°C.

Rainfall and river flow {Chapter 10, Section 10.3.2}

Freshwater and estuarine fish species are expected to be exposed to projected increases in rainfall and river flow in the tropics, and decreases in the subtropics {Chapters 2 and 7}. These species are likely to respond positively to the increases in water quality and habitat area resulting from higher rainfall and greater flows. On the other hand, negative responses are expected where rainfall and flow are reduced. River flows, in particular, have a strong effect on the production of freshwater and estuarine species through effects on habitat availability, nutrient transport, food web processes and cues for migration. Pacific Island countries and territories with increased river flows are therefore expected to yield greater catches, whereas those with more variable rainfall, such as New Caledonia, are expected to have more uncertain catches.

Sea level and salinity {Chapter 10, Section 10.3.3}

The fish and invertebrate species inhabiting lowland rivers and estuaries are expected to be highly exposed to projected sea-level rise {Chapter 3} and associated increases in salinity. Changes in salinity will be greatest in drought years when salt water penetrates further inland. Estuarine species are unlikely to be sensitive to these changes, whereas freshwater species in lowland areas are expected to have high sensitivity. The capacity of fish and invertebrates in lowland river habitats to adapt to the effects of sea-level rise will depend on their salinity tolerances. Changes in species composition can be expected to occur, with estuarine species expected to replace freshwater fish and invertebrates in existing lowland reaches.

Dissolved oxygen {Chapter 10, Section 10.3.4}

Freshwater and estuarine fish and invertebrates are expected to be exposed to projected decreases in dissolved oxygen (O_2) because oxygen solubility decreases with higher temperatures and salinities, although the projected decline in oxygen availability is expected to be small in most habitats. However, oxygen demand by fish and invertebrates increases with increasing water temperature and sensitivity of freshwater fish and invertebrate species to changes in O_2 will depend on their preferred habitats and their tolerance to oxygen depletion. Potential impacts include limits to recruitment and increases in invasive fish species that tolerate low oxygen levels. Some fish species have physiological adaptations to low oxygen, such as increased blood-oxygen affinity or accessory air-breathing organs. Other species have behavioural adaptations such as avoidance of hypoxic habitats or the ability to respire from the air-water interface. In locations with low flow where the combination of increased temperature and salinity combine to reduce O_2 significantly, fish assemblages are likely to be dominated by hypoxia-tolerant species.

Turbidity {Chapter 10, Section 10.3.5}

Exposure of freshwater and estuarine fish and invertebrates to increased turbidity under future climatic conditions will depend on the state of catchment vegetation. Rivers draining catchments where vegetation is intact are likely to experience only minor increases in turbidity due to limited transport of sediments in runoff. However, in catchments that have been extensively cleared, the projected increases in rainfall are expected to cause some naturally clear streams to become permanently turbid. Heavy suspended sediment loads can damage the gill epithelium of fish and affect respiration. Increased deposition of sediments reduces the reproductive success of species with adhesive demersal eggs. Fish in naturally turbid rivers will be less sensitive to changes in turbidity than those in naturally clear habitats. Potential impacts include reduced recruitment success by some fish species and reduced growth and survival of fish with a high dependence on visual feeding. The capacity of freshwater fish to adapt to increased turbidity will depend on the species and the prevailing environmental conditions.

Vulnerability of freshwater and estuarine fisheries to the indirect effects of climate change

Habitat changes {Chapter 10, Section 10.4.1}

Freshwater and estuarine fish and invertebrates are also expected to be exposed to climate change through projected alterations to their habitats as a consequence of new patterns of rainfall and river flow, and higher temperatures {Chapter 7}. Fisheries species are likely to be highly sensitive to these changes because they depend on a range of habitats within rivers, lakes, floodplains and estuaries for shelter and food. The potential effects include (1) increased yields of fish from lowland river areas as the extent of floodplain habitat expands due to higher rainfall; (2) greater fish production from the increased estuarine areas expected to be created by rising sea levels; and (3) lower catches of coldwater species such as rainbow trout and snow trout in the highlands of PNG as the extent of their habitat is reduced due to higher air temperatures. The capacity of fish and invertebrates to take advantage of increased floodplain habitat will depend on removing any barriers to movement of animals into the additional habitat. It will also depend on maintaining catchment vegetation in good condition to prevent erosion and pollution.

Overall vulnerability

Freshwater and estuarine fish and invertebrates are expected to have a low overall vulnerability to the direct and indirect effects of climate change, except in disturbed catchments (Table 6.13). Indeed, the effets of climate change on these species are expected to be positive.

The greatest benefits of climate change for freshwater and estuarine fisheries are expected to result from increases in rainfall and river flow, which increase habitat availability and quality, provide cues for fish migration, and enhance reproduction and recruitment. Production of freshwater fish and invertebrates in the tropical Pacific is projected to increase under both scenarios in 2035 and 2100. Changes are expected to be negligible or negative in locations where rainfall is projected to decrease.

Table 6.13 Vulnerability of freshwater and estuarine fisheries to projected changes in climate in well-managed and disturbed catchments.

	Temperature	River flow	Salinity	Dissolved oxygen	Turbidity
Well-managed catchments	Moderate	Very low	Low	Low	Low
Disturbed catchments	High	Low/High[a]	Moderate	Moderate	Moderate

a = H igh vulnerability applies only to substrate-spawning species.

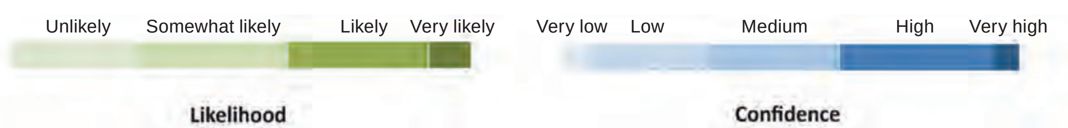
Projected changes in fisheries productivity

Ultimately, the projected changes in freshwater production are expected to translate into additional fisheries catches (Table 6.14). However, catches are likely to be reduced in disturbed catchments where human activities have increased the vulnerability of fisheries species to climate change.

Table 6.14 Projected change in production of freshwater and estuarine fisheries from well-managed catchments under B1 and A2 emissions scenarios in 2035 and 2100, relative to 2010.

Scenario	Freshwater and estuarine fisheries production (%)
B1/A2 2035	0 to +2.5
B1 2100*	-2.5 to +7.5[a]
A2 2100	0 to +12.5[a]

* Approximates A2 in 2050; a = fisheries production lower values are only for New Caledonia and all other PICTs are projected to show a productivity increase by 2100.



6.11 Vulnerability of aquaculture in the tropical Pacific to climate change {Chapter 11}[20]

Aquaculture has considerable potential to contribute to food security and sustainable livelihoods in the tropical Pacific. A wide range of aquaculture activities are currently underway in 16 Pacific Island countries and territories (PICTs). In general, freshwater aquaculture activities focus on producing commodities for food security, whereas those in coastal waters are usually aimed at creating livelihoods.

The species used to produce aquaculture commodities are potentially vulnerable to changes in surface climate {Chapter 2}, the ocean {Chapter 3} and coastal habitats {Chapters 5 and 6}. The vulnerability of aquaculture operations to climate change, in terms of the exposure and sensitivity of the species involved, the potential impact of these changes, the capacity of the species to adapt, and the exposure of infrastructure, is summarised below.

Vulnerability of aquaculture commodities for food security

Tilapia and carp {Chapter 11, Section 11.3.1.1}

Aquaculture operations for tilapia and carp are expected to be exposed to projected increases in water temperature and rainfall. Low-lying tilapia ponds near the coast are also expected to be exposed to sea-level rise and possibly more intense cyclones. These farming activities are expected to be sensitive to these changes because temperature regulates growth and reproduction of tilapia and carp, and rainfall modulates water temperature and water exchange (and its effect on dissolved oxygen levels) in ponds. Aquaculture operations for tilapia and carp are expected to benefit from the projected increases in temperature and rainfall as growth rates increase and the more locations become suitable for pond aquaculture. However, care will be needed to construct ponds where they are not prone to flooding under higher rainfall conditions, or to inundation or damage from sea-level rise or storm surge. Potential negative impacts could occur if climate change limits the supply of fishmeal from overseas, or increases the risk of fish diseases. Tilapia and carp farming operations have a high capacity to be adapted to a changing climate because stocking densities can be altered to suit the prevailing conditions and availability of fish feeds. However, intensive culture systems that rely on high stocking densities have a lower adaptive capacity than extensive farming operations.

Milkfish {Chapter 11, Section 11.3.1.2}

Aquaculture activities based on farming milkfish in ponds are likely to have a similar vulnerability to that of tilapia culture. Milkfish are expected to be exposed to projected increases in water temperature and rainfall. Low-lying ponds near the coast could also be exposed to sea-level rise and possibly more intense cyclones.

Ocean acidification and changes in coastal habitats {Chapters 3 and 6} could also affect the supply of the wild-caught fry used to stock ponds. Milkfish are expected to be sensitive to increases in temperature because it regulates growth and reproduction of fish in shallow ponds. They are also expected to be sensitive to changes in rainfall because rain can modulate water temperature and water exchange in ponds. The projected increases in temperature are expected to increase the production of milkfish due to faster rates of growth, and extend the geographical range and season for capturing wild juveniles. Greater rainfall should increase the number of areas where ponds can be constructed. However, some potential impacts are possible if climate change limits the supply of fishmeal to formulate diets, or increases the risk of fish diseases. Milkfish farming based on the collection of wild fry may be able to adapt to the greater projected variability in the supply of juveniles by producing juveniles in hatcheries. Low-lying ponds near the coast vulnerable to sea-level rise and storm surge can be relocated further inland. However, both these adaptations require substantial investment.

Vulnerability of aquaculture commodities for livelihoods

Pearls {Chapter 11, Section 11.3.2.1}

Pearl oysters will be exposed to projected increases in sea surface temperature (SST), decreases in salinity due to changing rainfall patterns in some locations, ocean acidification, sea-level rise and possibly more intense cyclones. Both the black-lipped and white-lipped pearl oysters are sensitive to increases in SST because it increases their susceptibility to pathogens and parasites and affects nacre deposition and pearl quality. Reduced salinity and increased sedimentation associated with rainfall events can cause mass mortality of pearl oysters. Ocean acidification is expected to affect the survival and growth of spat, calcification of shells and pearl quality. The effects of sea-level rise and more intense cyclones may increase the exposure of pearl farm infrastructure to damage. Pearl farming operations have considerable capacity to adapt to the changes ahead. Options include increasing the proportion of spat produced in hatcheries under controlled temperature and pH conditions; placing oysters in deeper, cooler water; harvesting pearls during cooler months to avoid extreme SST; growing pearl oysters at microsites where concentrations of carbon dioxide in sea water are reduced; and designing infrastructure to withstand intense cyclones. Such adaptations will increase operational costs.

Shrimp {Chapter 11, Section 11.3.2.2}

Shrimp farming will be exposed to projected increases in temperature, changes in rainfall, sea-level rise, ocean acidification and possibly stronger storm surge from more severe cyclones. The species of shrimp grown in New Caledonia is expected to be sensitive to increasing, or more variable, water temperature and reductions in rainfall. Potential impacts include the greater risk of temperature-related diseases, deteriorating water quality during times of extremely high rainfall and problems in drying out ponds between production cycles. Sea-level rise is also expected to impede the draining of ponds, to remove the anoxic sediment layer, which reduces growth and survival of shrimp during the next production cycle. However, shrimp farming may benefit in the shorter term from increasing temperatures that increase growth rates and improve yields. Shrimp farming enterprises can adapt to the effects of sea-level rise by adding soil to the floor of ponds and increasing the height of the walls so that ponds continue to drain efficiently. Ultimately, new ponds may need to be constructed at higher elevations, and shrimp may need to be farmed more intensively. In more tropical areas, the warming conditions may enable the shrimp farming industry to grow a wider variety of species.

Seaweed {Chapter 11, Section 11.3.2.3}

Seaweed farming is expected to be exposed to projected increases in SST and rainfall, ocean acidification, sea-level rise, and possibly more intense cyclones. The *Kappaphycus* seaweed grown in the region is sensitive to increased SST and reduced salinity, which stress the plants and inhibit growth. More intense cyclones would cause great damage to the equipment used to grow seaweed. The expected increase in SST is likely to result in crop losses due to increased incidence of outbreaks of epiphytic filamentous algae and tissue necrosis. Lower salinities caused by increased rainfall are likely to reduce the number of sites where seaweed can be grown. On the other hand, higher levels of carbon dioxide (resulting in ocean acidification) and sea-level rise may benefit seaweed farming by stimulating growth and promoting water exchange. There is limited scope for adaptation of seaweed farming at the regional level by shifting production to higher latitudes.

Marine ornamentals {Chapter 11, Section 11.3.2.4}

Marine ornamental aquaculture is expected to be exposed to projected increases in SST, changes in rainfall, ocean acidification, sea-level rise, degradation of habitats and possibly more intense cyclones. The main species used for marine ornamental products, corals and giant clams, are expected to be sensitive to increased SST. Higher temperatures are likely to affect the growth and survival of cultured corals and giant clams grown in the sea (due to more regular bleaching). These species are also sensitive to changes in salinity and turbidity associated with higher rainfall, and reduced aragonite saturation levels caused by ocean acidification. As a result, the conditions for producing the main marine ornamental products are eventually expected to deteriorate. In some locations, sea-level rise could reduce the potential impact by improving water exchange and nutrient supply to oligotrophic sites. Possible adaptations involve transferring operations from the sea to recirculating tanks on land, where water temperature and pH can be controlled, and developing markets for species of coral that are likely to be more tolerant to changing environmental conditions.

Freshwater prawns {Chapter 11, Section 11.3.2.5}

Freshwater prawn aquaculture is expected to be exposed to projected increases in water temperatures and rainfall, and the possible effects of more intense cyclones. Freshwater prawns are sensitive to increases in water temperature and the potential effects include increased growth, provided temperatures remain within thermal limits. The projected increases in rainfall should increase availability of freshwater and provide opportunities to farm freshwater prawns in a greater range of locations. The expected expansion of freshwater habitats should also provide a greater abundance of wild juveniles for grow-out operations. Adaptations to reduce any adverse effects of warmer pond temperatures centre on constructing ponds in locations where they have high water turnover rates.

Marine fish {Chapter 11, Section 11.3.2.6}

The sensitivity of hatchery-based marine fish aquaculture operations to the projected changes in SST is expected to be low because these operations rely on environmentally controlled facilities to mature broodstock and rear the juveniles. However, collection of wild juvenile rabbitfish for grow-out may be sensitive to the effects of SST on the spawning cycle of the adults. The sensitivity of marine fish grown in sea cages to the projected increase in SST is likely to be similar to the responses of demersal fish associated with coastal habitats, i.e. metabolic rates are expected to increase {Chapter 9}. Depending on the species and location of operations, growth could be inhibited under the A2 emissions scenario by 2100. The potential impact of climate change on prospective marine fish species, or the infrastructure needed to produce them, is estimated to be low because the possible effects can be taken into account when assessing the suitability of local and projected environmental conditions for establishment of hatcheries and sea cages. A possible longer-term effect is that once sites are selected, fish may need to be fed a greater daily ration due to their higher rates of metabolism in warmer waters.

Sea cucumbers {Chapter 11, Section 11.3.2.7}

The sea ranching and/or farming of sea cucumbers is expected to be exposed to projected increases in air temperature and SST, increased rainfall, ocean acidification, sea-level rise, changes to seagrass habitats, and possibly increasing cyclone intensity. These operations are expected to be sensitive to many of these consequences of climate change. Higher water temperatures, reduced salinity and ocean acidification could affect the success of sea ranching operations by increasing the mortality of juveniles and degrading the seagrass habitat {Chapter 6} where hatchery-reared juveniles need to be released. Pond farming in subtropical areas is expected to benefit from the faster growth rates of sea cucumbers reared in warmer water. However, sea cucumbers grown in ponds in the tropics may suffer higher mortality due to the increased likelihood of stratification caused by higher rainfall and reduced salinity. In locations where farming sea cucumbers in ponds proves to be profitable, adaptations can be made to hatchery operations to control the temperature, salinity and pH of the water. The construction of ponds for growing sea cucumbers to market size can be modified to maximise mixing.

Trochus {Chapter 11, Section 11.3.2.8}

The production of trochus for restocking programmes is expected to be exposed to projected increases in SST, lower salinity due to more rainfall, ocean acidification, sea-level rise and possibly increases in cyclone intensity. The future success of restocking programmes based on release of hatchery-reared juveniles is likely to be sensitive to lower salinity, sea-level rise and more intense cyclones. The salinity of the shallow rock pool habitats used by trochus is expected to decrease beyond their tolerance in some locations and sea-level rise is likely to reduce the availability of this habitat where intertidal areas are prevented from moving landward. Powerful waves from cyclones are likely to cause high mortality of trochus released on reefs unless these trochus have reached the size where they move to deeper water. The possible effect of ocean acidification on the strength of trochus shells remains to be determined. The key adaptation for restocking programmes will be to place more emphasis on translocation of mature adult trochus to form breeding populations. Where hatchery-reared animals are required, they should be released at the largest size possible to reduce the need to use intertidal areas as release sites.

Overall vulnerability

When the direct effects of the projected changes to water temperature, rainfall, ocean acidification, sea-level rise, cyclone intensity, and the expected indirect effects of alterations to habitats, are integrated it is evident that:

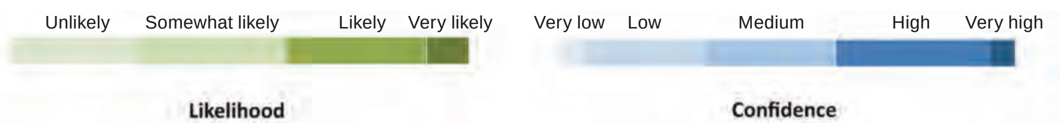
1. existing and planned aquaculture activities to produce tilapia, carp and milkfish in freshwater ponds for food security are likely to benefit from the anticipated changes to surface climate; and
2. aquaculture enterprises producing commodities for livelihoods in coastal waters are likely to encounter production problems due to changes projected to occur in the tropical Pacific Ocean.

Aquaculture operations for tilapia, carp and milkfish are expected to benefit strongly from projected increases in temperature and rainfall, and to cope with other changes to the environment even though some are negative. These projected benefits are expected to be apparent by 2035 (Table 6.15), and well established by 2100, especially under the A2 emissions scenario, when surface temperatures are expected to be 2.5–3.0°C higher, and rainfall 10–20% greater, in tropical areas relative to 1980–1999 {Chapter 2}. A proviso is that the changing climate does not limit access to the ingredients needed to formulate appropriate diets for tilapia, carp and milkfish, particularly fishmeal.

Table 6.15 Vulnerability of aquaculture commodities to projected climate change under the B1 and A2 emissions scenarios in 2035 and 2100.

Commodity	Vulnerability		
	B1/A2 2035	B1 2100*	A2 2100
Food security			
Tilapia and carp	L (+)	L-M (+)	M (+)
Milkfish	L (+)	L (+)	L (+)
Livelihoods			
Pearls	L (-)	L (-)	M (-)
Seaweed	M (-)	M-H (-)	H (-)
Shrimp	L (+)	L (-)	L–M (-)
Marine ornamentals	L (-)	M (-)	H (-)
Freshwater prawn	L (+)	L (-)	L (-)
Marine fish	L (-)	L (-)	L-M (-)
Sea cucumbers	L (-)	L (-)	L-M (-)
Trochus	L (-)	L (-)	L (-)

* Approximates A2 in 2050; L = low; M = moderate; H = high.



The enhanced conditions for freshwater pond aquaculture expected as a result of climate change by 2035 should also apply to the farming of freshwater prawns. However, the benefits for farming freshwater prawns may be reversed by 2100 due mainly to the temperature sensitivity of the prawns and the effects of higher temperatures on stratification of ponds.

Although some commodities for livelihoods are likely to benefit from the projected changes in specific environmental variables, when the effects of all variables are integrated, most commodities produced in coastal waters are expected have a low vulnerability by 2035 (Table 6.15). The exceptions are shrimp and seaweed. For shrimp farming in 2035, the expected benefits from the projected increases in water temperatures may well improve yields. For seaweed farming, the expected increases in SST and rainfall by 2035 are likely to mean that the industry has a moderate rather than low vulnerability to crop losses due to increased incidence of outbreaks of epiphytic filamentous algae and tissue necrosis.

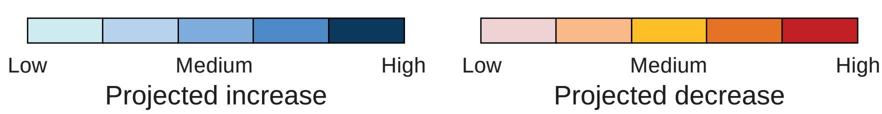
By 2100, the effects of climate change and ocean acidification on all livelihood commodities are expected to be negative (Table 6.15). Under the A2 emissions scenario, seaweed farming and production of marine ornamentals are likely to have a high vulnerability, and the culture of pearls is expected to be moderately vulnerable to such conditions. Shrimp farming, marine fish culture and sea ranching/pond farming of sea cucumbers are all expected to have a low to moderate vulnerability to the A2 scenario by 2100. The vulnerability of trochus is rated as low until further research elucidates how they acquire calcium carbonate to construct their shells.

Vulnerability does not necessarily imply that there will be overall reductions in productivity of coastal aquaculture commodities in the future. Rather, it indicates that the efficiency of enterprises producing the commodity are likely to be affected (Table 6.16). Total production could still increase if the operations remain viable, and more enterprises are launched. For example, seaweed production targets that have been set for the next decade of 1000–2000 tonnes per year (engaging several hundred households) in both Fiji and Solomon Islands should still be achievable, but not necessarily in the same places or with the methods now in use.

Table 6.16 Projected changes in efficiency of aquaculture operations under B1 and A2 scenarios in 2035 and 2100, relative to 2010.

Aquaculture commodity	Vulnerability		
	B1/A2 2035	B1 2100*	A2 2100
Food security			
Tilapia and carp	↑	↑	↑
Milkfish	↑	↑	↑
Livelihoods			
Pearls	↓	↓	↓
Seaweed	↓	↓	↓
Shrimp	↑	↓	↓
Marine ornamentals[a]	↓	↓	↓
Freshwater prawn	↑	↓	↓
Marine fish	↓	↓	↓
Sea cucumbers	↓	↓	↓
Trochus	↓	↓	↓

* Approximates A2 in 2050; a = includes coral fragments, live rock and giant clams.



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Abbreviations

AR	Assessment Report
ARCH	Archipelagic Deep Basins
AusAID	Australian Agency for International Development
BMP	best management practice
CEAFM	community-based ecosystem approach to fisheries management
CMIP	Coupled Model Intercomparison Project
CNMI	Commonwealth of the Northern Mariana Islands
CO_2	carbon dioxide
DNA	deoxyribonucleic acid
DWFNs	distant water fishing nations
EAC	East Australian Current
EEZ	exclusive economic zone
ENSO	El Niño-Southern Oscillation
EPA	Economic Partnership Agreement
EU	European Union
EUC	Equatorial Undercurrent
FADs	fish aggregating devices
FSM	Federated States of Micronesia
GDP	gross domestic product
GIFT	genetically improved farmed tilapia
GIS	geographic information system
GR	government revenue
HadISST	Hadley Centre Global Sea Ice and Sea Surface Temperature
HE	Halmahera Eddy
IATTC	Inter-American Tropical Tuna Commission
ICESCR	International Covenant on Economic, Social and Cultural Rights
IEPA	Interim Economic Partnership Agreements
ITF	Indonesian Throughflow
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institut Pierre Simon Laplace
ITCZ	Intertropical Convergence Zone
IUU	illegal, unreported and unregulated
KURO	Kuroshio Current
MC	Mindanao Current
ME	Mindanao Eddy
MLD	mixed layer depth
NAPAs	national adaptation programmes of action
NCJ	North Caledonian Jet
NEC	North Equatorial Current
NECC	North Equatorial Counter Current
NGCUC	New Guinea Coastal Undercurrent
NGO	non-governmental organisation

NPP	net primary production
NPTG	North Pacific Tropical Gyre
NQC	North Queensland Current
NSTCC	North Subtropical Counter Current
NVJ	North Vanuatu Jet
O_2	oxygen
PaCFA	Global Partnership for Climate, Fisheries and Aquaculture
PAR	photosynthetically active radiation
pCO_2	partial pressure of carbon dioxide
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PDO	Pacific Decadal Oscillation
PEQD	Pacific Equatorial Divergence
PICTs	Pacific Island countries and territories
PNA	Parties to the Nauru Agreement
PNG	Papua New Guinea
ppm	parts per million
SAM	Southern Annular Mode
SCJ	South Caledonian Jet
SEAPODYM	Spatial Ecosystem and Population Dynamics Model
SEC	South Equatorial Current
SECC	South Equatorial Counter Current
SPC	Secretariat of the Pacific Community
SPCZ	South Pacific Convergence Zone
SPSG	South Pacific Subtropical Gyre
SST	sea surface temperature
SSTCC	South Subtropical Counter Current
SWH	significant wave height
TAO	Tropical Atmosphere Ocean
USD	United States dollar
UVR	ultraviolet radiation
VDS	vessel day scheme
Warm Pool	Western Pacific Warm Pool
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean
WCRP	World Climate Research Programme
WGCM	Working Group on Coupled Modelling