Published in: Bell JD, Johnson JE and Hobday AJ (eds) (2011) Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat of the Pacific Community, Noumea, New Caledonia.

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Chapter 13

Adapting tropical Pacific fisheries and aquaculture to climate change: Management measures, policies and investments

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'Fisheries policy makers should now turn their attention to the development and implementation of climate change adaptation strategies.' (Davis 2010)[i]

i Davis JC (2010) Chair's summary. In: *The Economics of Adapting Fisheries to Climate Change*. OECD Publishing, Paris, France, pp. 17–28.

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13.1 Introduction

The main purpose of this book is to assess how changes projected to occur under low (B1) and high (A2) emissions scenarios in 2035 and 2100 could derail plans by the Pacific Island countries and territories (PICTs) to use the sustainable benefits of fisheries and aquaculture to foster economic development, government revenue, food security and livelihoods[1,2] (Chapters 1 and 12).

These plans already involve adaptation responses ('adaptations') and policies to address other important influences on fisheries and aquaculture, especially population growth and the associated demand for more employment. However, it is clear that the projected changes to surface climate and the tropical Pacific Ocean (Chapters 2 and 3), fish habitats (Chapters 4–7), and fisheries and aquaculture production (Chapters 8–11), could affect the plans to maximise sustainable benefits from the sector. In particular, the consequences of global warming and ocean acidification may impede some aspects of these plans, whereas other effects of climate change could bring important benefits (Chapter 12).

Fisheries managers throughout the region will need to strengthen existing and planned adaptations, and launch new interventions, to minimise threats and harness opportunities associated with the direct and indirect effects of climate change on oceanic, coastal and freshwater fisheries, and aquaculture (Chapters 8–11).

Considerations that frame the identification of practical adaptations are (1) the extraordinary reliance of PICTs on fisheries and aquaculture (Chapter 12); (2) the wide range of fisheries in the region, from globally significant industrial tuna fleets to subsistence and small-scale commercial activities with very high levels of participation; and (3) the emphasis on governance of national and regional industrial tuna fishing, but frequent neglect of small-scale fisheries crucial to food security and livelihoods[2–4] (Chapters 1 and 12).

Adaptations for fisheries and aquaculture must also complement those proposed by other sectors (e.g. agriculture and forestry) to diversify the range of options for producing food and earning income[5,6]. The greater the number of production systems available to communities, the greater the probability that some systems will not be affected, and may even be favoured, by the changing climate.

This chapter sets out the information needed by stakeholders in the fisheries and aquaculture sector at all levels to reduce the threats and capitalise on the opportunities created by climate change. In particular, we:

- outline the existing management regimes and initiatives for industrial and small-scale fisheries and aquaculture in the region to secure desired human development outcomes and maintain healthy fish stocks;

- identify an appropriate framework for selecting practical adaptations to address the key near-term drivers for fisheries and aquaculture, and the future effects of climate change;
- recommend adaptations, and suggest policy approaches, to maximise the contributions of fisheries and aquaculture to economic development, government revenue, food security and livelihoods as the climate changes;
- outline the value of modelling to examine interactions among adaptation options;
- explain the need to monitor the projected effects of climate change on the sector;
- summarise the gaps in knowledge to be filled to improve understanding of the vulnerability of fisheries and aquaculture in the tropical Pacific to climate change, and to fine-tune key adaptations;
- identify priority investments needed to apply the main adaptations, fill gaps in knowledge, strengthen partnerships, monitor the projected effects of climate change and measure the success of adaptations; and
- consider sources of funding to make the necessary investments.

We emphasise that adaptations and policies to build the resilience of the Pacific communities to climate change should not be viewed just from a scientific or technical perspective – the needs and aspirations of people must also be integrated[7,8]. Understanding how people are affected, and how their traditional knowledge, capacities and perspectives can help develop and implement adaptations is a vital part of the process. Community[ii] consultation and participation are essential to ensure that adaptations incorporate a human rights and human development approach to achieve gender equality, maintain relevant traditional customs and culture, and empower young people[9–13].

13.2 Existing management regimes and approaches

13.2.1 Oceanic fisheries

Pacific Island countries and territories are acutely aware that their aspirations to maximise the economic and social benefits of the region's rich oceanic fisheries resources[14,15] are tied to sound cooperative management of the transboundary stocks of tuna and associated large pelagic fish (Chapters 1, 8 and 12).

Cooperative management of oceanic fisheries was launched in 1979, with the formation of the Pacific Islands Forum Fisheries Agency (FFA)[iii]. FFA coordinates policy advice and technical support to assist members of the Pacific Islands Forum

ii Community refers to the men, women and children who participate in catching, processing and selling fish.

iii www.ffa.int

manage fishing effort by distant water fishing nations (DWFNs) and domestic fleets within their exclusive economic zones (EEZs). The Forum Fisheries Agency has developed a 'Regional Tuna Fisheries Management and Development Strategy', which it implements on behalf of its member countries. This strategy is a set of shared principles for the sustainable management of oceanic fish stocks and ecosystems, and economic development based on tuna fisheries[16]. The key management measures and treaties developed by FFA for its members are summarised in **Table 13.1**.

Because ~ 25% of the world's tuna catch comes from the EEZs of the Parties to the Nauru Agreement (PNA)[iv] (Chapters 1 and 8), purse-seine fishing effort across these zones is allocated by the Director of the PNA Office through the vessel day scheme (VDS) under amendments to the Palau Arrangement (**Table 13.1**). The PNA Office in Marshall Islands also explores collective ways to increase the contributions of tuna resources to the economic development of its members[17]. In a similar move, the Polynesian countries have launched the Te Vaka Moana Arrangement (TVMA) to harmonise management approaches, exchange information and optimise the benefits from longline fishing for tuna in their EEZs.

The transboundary nature of the region's oceanic fisheries resources, which also allows them to be captured on the high seas, calls for a broader approach. In response to the need to manage tuna stocks across the entire Western and Central Pacific Ocean (WCPO), the Convention for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean was declared in 2004[v]. The Western and Central Pacific Fisheries Commission (WCPFC)[vi] was established to administer this convention. Pacific Island countries and territories engage with DWFNs, and other countries that harvest tuna in the WCPO, such as the Philippines and Indonesia, through the WCPFC to manage and conserve the region's oceanic fisheries resources.

Members of FFA, PNA and TVMA[vii] cooperate to control catch and effort within the WCPO to maintain stocks of skipjack, yellowfin, bigeye and South Pacific albacore tuna at levels that ensure conservation of these valuable resources, as well as sustainable economic benefits. Examples of management measures implemented by PNA and supported by FFA and WCPFC to address recent overfishing of bigeye tuna are provided in Chapters 1 and 12. Other measures have been suggested to improve both economic benefits and long-term conservation[18].

The management arrangements are underpinned by regular, in-depth stock assessments for all four species of tuna (Chapter 8). These stock assessments involve extensive collection of data on catch and fishing effort, sampling of catches, biological

iv www.pnatuna.com

v www.wcpfc.int/key-documents/convention-text

vi www.wcpfc.int

vii See Chapter 1 for the members of FFA, WCPFC and PNA. The members of TVMA are Cook Islands, New Zealand, Niue, Samoa, Tokelau and Tonga.

research and tagging studies by the Oceanic Fisheries Programme at the Secretariat of the Pacific Community[viii]. Research is also underway on the open ocean food webs that support tuna[19,20] (Chapter 4), and the effects of industrial tuna fisheries on the bycatch of other large pelagic fish[21,22]. The costs of this research are justified by the significance and value of tuna catches in the WCPO, which totalled ~ 2.5 million tonnes in 2009, worth > USD 4 billion[23] (Chapters 1 and 8).

Table 13.1 The main measures developed and implemented by the Pacific Islands Forum Fisheries Agency to manage tuna fisheries for its member countries.

Measure	Key features
National tuna fishery development plans	Promotes sustainable national tuna fisheries, using the ecosystem-based approach to fisheries management[16,118,119].
Nauru Agreement	Specifies terms and conditions for tuna purse-seine fishing licences in the region. The agreement has various implementing arrangements, including the FSM Arrangement and Palau Arrangement.
FSM Arrangement*	Provides for preferential access by vessels sponsored by the Parties of the Nauru Agreement (PNA) to each others' EEZs[120].
Palau Arrangement*	Provides a suite of measures for cooperative management of the purse-seine and longline fisheries in the EEZs of PNA members, including the vessel day scheme (VDS), as well as agreed policies on licensing conditions, crewing and the operation of vessel monitoring schemes and observer programmes[63].
US Treaty	A multilateral fisheries access agreement between FFA members and the USA, which provides fishing opportunities for up to 40 US-flagged purse-seine vessels (and up to an additional five vessels under joint venture arrangements) in the treaty area, in return for funding.
Monitoring, Control and Surveillance	Agreed policies for the detection and deterrence of illegal, unregulated and unreported fishing. The tools include the Pacific Islands Regional Fishery Observer Programme, the Regional Vessel Monitoring System, the Regional Register of Fishing Vessels and the Niue Treaty for cooperation in fisheries surveillance and information sharing[121,122].

* Measures now transferred to PNA.

13.2.2 Coastal fisheries

Coastal fisheries in the tropical Pacific differ fundamentally from the industrial tuna fisheries in at least two ways. First, they are based on hundreds of species of demersal fish and invertebrates[24,25] (Chapter 9), very few of which yield sufficient economic and social benefits to justify the type of stock assessments made for tuna. Second, self-replenishing populations of most coastal species are restricted to individual PICTs, or even smaller spatial scales (Chapter 9). For this reason, stocks of coastal fish and invertebrates do not often represent transboundary resources, although some stocks are likely to be shared, for example, between PNG and Solomon Islands, PNG and Australia, and American Samoa and Samoa. These features of coastal fisheries, combined with the limited scientific capacity in the national agencies of most PICTs, have resulted in much uncertainty about the sustainable harvest levels and status of coastal fisheries (Chapter 9).

viii www.spc.int/oceanfish

The exceptions are (1) the easily-accessible, sedentary invertebrates, such as sea cucumbers and trochus that are harvested from shallow water and targeted for export commodities; and (2) the component of the nearshore pelagic fishery comprising skipjack and yellowfin tuna caught by subsistence and small-scale commercial fishers (Chapter 9). Dramatic declines in exports of sea cucumbers and trochus show that these valuable resources have been chronically overfished in many PICTs[25–27] (Chapter 9). The reasonably good understanding of the nearshore pelagic fish component of coastal fisheries comprised of tuna stems from the strong overlap between coastal and industrial fisheries in the region. Investments in quantitative stock assessments for tuna have produced good estimates of the status of these species (Chapter 8).

Against this backdrop, it is unlikely that PICTs will develop and implement conventional stock assessments for many species of demersal fish and invertebrates. Arguably, any attempt to do so would not be cost-effective because such approaches would not make the best use of the social capital and natural history knowledge of coastal communities. Alternative ways of assessing the status of fisheries in data-poor situations exist[28,29]. Pacific Island countries and territories have a long tradition of community-based approaches to fishery management[30] and strengthening this approach is broadly seen as offering the best hope of securing coastal fisheries resources for the future[2,31,32]. In much of Melanesia, community-based approaches to fisheries management are also favoured by long-standing customary marine tenure[33–36], which helps to ensure that benefits accrue directly to communities.

The search for innovation under the broad umbrella of community-based management is likely to remain a critical frontier for communities, national agencies, regional organisations and non-governmental organisations (NGOs)[28,37–39]. Confronting habitat degradation caused by agriculture, forestry (logging) and mining activities in catchments (Chapters 5–7), and overfishing due to population growth and other economic and social drivers[2,40–42] (Chapter 12), present the two greatest challenges.

Many PICTs need to produce more fish from their coastal waters for national food security (Chapter 12). However, management that aims to avoid further depletion of overfished stocks is likely to be more appropriate in the short term than management aimed at maximising sustainable production. Using 'primary' fisheries management[ix] to limit catches to avoid irreversible damage to stocks in the face of uncertainty[38], and investing in the social capital and institutions needed for communities and governments to manage coastal fisheries[28], are high priorities. Unfortunately, the projected increases in coral bleaching due to global warming and degradation of coral reefs from ocean acidification (Chapter 5) are expected to increase uncertainty, demanding an even more precautionary approach[29] and further reducing responsible yields from coastal fisheries (**Figure 13.1**).

ix Primary fisheries management recognises the need to use simple harvest controls, such as size limits, closed seasons and areas, gear restrictions and protection of spawning aggregations. Secondary and tertiary fisheries management require greater investments in stock assessments to reduce uncertainty about the economic benefits that can be gained from more accurate and precise estimates of sustainable harvests.

To equip PICTs with a practical way of managing coastal fisheries in the face of the many drivers influencing the sector, a 'community-based ecosystem approach to fisheries management' (CEAFM) is being developed for the region[32]. CEAFM merges the well-recognised need for an ecosystem approach[43,44] and primary fisheries management based on co-management through strong community involvement. Implementing CEAFM requires a legal framework and the involvement of many stakeholders to support communities and national agencies, particularly regional fisheries and environmental organisations and NGOs.

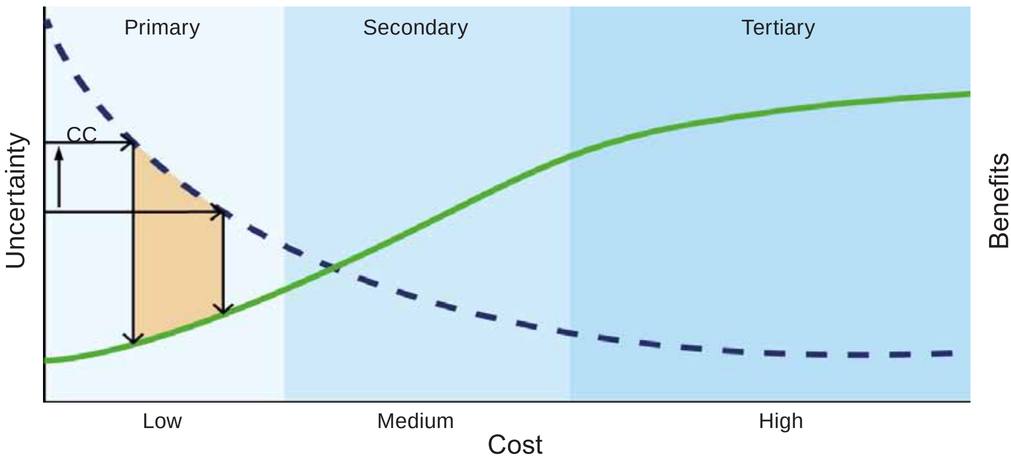

Figure 13.1 General relationship between potential benefits from fisheries for coastal demersal fish species and invertebrates (green line), and uncertainty in information for management (blue line), as functions of costs, for primary, secondary and tertiary fisheries management (source: Cochrane et al. 2010)[38] (see also footnote on page 809). The reduction in benefits under primary fisheries management as a result of the increased uncertainty caused by climate change (CC) is indicated by the orange shading.

13.2.3 Freshwater and estuarine fisheries

The freshwater and estuarine fisheries of the tropical Pacific are still poorly understood[3] (Chapter 10) and receive little or no attention from national fisheries departments and regional organisations. Primary fisheries management implemented through CEAFM, along the lines described above for coastal fisheries, is also needed to maintain the benefits of these fisheries for communities living beside rivers and lakes, mainly in Melanesia and particularly in Papua New Guinea (PNG). But the challenge is broader than that – best practice is required from agriculture, forestry and mining operations in catchments to avoid degrading freshwater fish habitats through additional sedimentation, excessive nutrients and pollution by toxic chemicals[45] (Chapter 7).

Management of freshwater fisheries in PNG must also address the risk of further invasive fish species. The freshwater fish fauna in PNG already includes a high proportion of introduced and invasive species. While many (but not all) of the introduced species are valued as food, other unwanted invasive species are reducing the availability of native fish species and the preferred introduced species (Chapter 10).

In contrast to demersal coastal fisheries, some freshwater fisheries are likely to be enhanced by climate change (Chapter 10). Projected increases in rainfall in the tropics (Chapter 2) in particular are expected to increase the area and inundation frequency of floodplain habitats (Chapter 7). Investments in primary fisheries management in freshwater and estuarine ecosystems are expected, therefore, to be operating under conditions more favourable to fisheries production, provided catchments are managed appropriately. As the areas available for catching freshwater and estuarine fish and invertebrates expand, it will be important to maintain traditional access and ownership rights, especially if the ownership of boats and fishing equipment by the growing populations in Melanesia increases.

13.2.4 Aquaculture

Pearl and penaeid shrimp farming are now mature industries (Chapter 11) in some PICTS, with private sector enterprises managed under government regulations producing high-quality exports[46]. The diverse range of exploratory and emerging aquaculture activities producing commodities for food security and livelihoods in many other parts of the region (Chapter 11) are generally operating under much looser management frameworks[3,47].

As existing activities develop and other economically viable prospects for aquaculture are identified, which is already occurring under the regional aquaculture action plan[47] and a series of national aquaculture plans (Chapter 11), PICTs will need to (1) develop national legislation to encourage investment, including licensing arrangements, guaranteed access to suitable sites, and support for pilot commercial projects; (2) implement global standards for aquatic animal health and biosecurity[48–51]; (3) set quality standards for products; (4) facilitate training in the technical and business skills needed to operate aquaculture enterprises efficiently; and (5) promote any competitive advantages they may have for aquaculture.

These measures are needed to create appropriate incentives and security for the private sector to establish substantial enterprises. They are also needed to create the large commercial operations that will be ‘vehicles’ for delivering benefits to smallholders, thereby assisting PICTs to meet their aspirations for the opportunities created by aquaculture to flow to communities. Thus, wherever appropriate, licensing conditions for large enterprises need to enable a significant proportion of production (e.g. spat collection and on-growing commodities to market size) to be out-sourced to smallholders. The main enterprise would focus on overseeing quality control and providing economies of scale for access to farm inputs needed by smallholders. Similar models have been used successfully to establish plantation agriculture and the production of chickens and eggs in the region.

13.2.5 A human rights approach

The community-based management approaches outlined in Sections 13.2.2 and 13.2.3 will be particularly effective when fishing rights closely support social, economic and human rights. Under such circumstances, small-scale coastal and freshwater fisheries can make a critical difference to food security and the broader aspirations of communities for well-being and socio-economic success[52]. People engaged in fishing who are more secure and less vulnerable can also be expected to be more effective and motivated participants in the co-management of resources. In short, treating the governance of small-scale fisheries in the region as an aspect of general human rights will encourage sustainable use of resources, and help achieve human development goals[53].

The security and well-being of coastal and freshwater fishing communities is best improved by social and political development that invokes the existing laws supporting the Universal Declaration of Human Rights[53]. In particular, the management of fisheries and aquaculture in the region should (1) secure rights to catch, process and sell fish for a broad spectrum of people from rural and urban communities; and (2) provide opportunities for equitable participation of women, children and other vulnerable groups in production and market chains in ways that remove customary and social inhibitions (i.e. rights need to be secured for the right people)[52,54]. Achieving these goals will require gender assessments and analysis.

13.3 A framework for selecting adaptations

The projected effects of climate change on the production of oceanic, coastal and freshwater fisheries and aquaculture (Chapters 8–11) are not the only likely influences on the future of the sector. Population growth and urbanisation, patterns of economic development, status of fisheries resources in other oceans, governance and political stability, markets and trade, fuel costs, technological innovation and foreign aid can all be expected to influence fisheries and aquaculture in the region[2,42,55]. Population growth and urbanisation are expected to be particularly significant, especially in Melanesia (Chapters 1 and 12).

Because most of these factors 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[56]. Clearly, the best investments are those that deliver short-term and long-term benefits ('win-win' adaptations) (**Figure 13.2**). Adapting to climate change will also involve some 'lose-win' adaptations – where the economic and social costs exceed the benefits in the near term, but where investments position PICTs to receive net benefits in the longer term under a changing climate. 'Win-lose' investments represent maladaptation to climate change and should be avoided, except in extreme cases where human survival may otherwise be compromised.

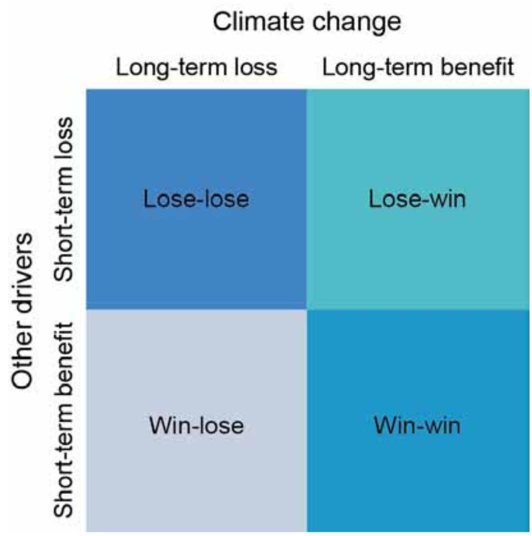

Figure 13.2 Decision framework for identifying adaptations to address climate change and other drivers (source: Grafton 2010)[56].

Identification of win-win and lose-win adaptations should not be based simply on the availability of technology and projected future responses of the resources underpinning fisheries and aquaculture. There are potential social barriers to the uptake of appropriate technology[57,58]. 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.

Ultimately, prospective adaptations within the decision framework should be assessed using formal cost:benefit analysis, based on the best available information and economic modelling, to determine the extent to which interventions will reduce threats from short-term and long-term drivers, and effectively capitalise on the opportunities. Such analysis is also needed to assess the opportunity costs of various adaptations.

In the section below, we outline the main prospective win-win and lose-win adaptations, in the expectation that PICTs and their development partners will undertake the cost:benefit analysis needed to confirm their suitability. We also suggest policies to support these adaptations.

13.4 Recommended adaptations and suggested supporting policies

The adaptations and policies recommended here are founded on the assumptions that (1) the key objectives of national agencies responsible for managing fisheries and aquaculture are to maximise sustainable benefits for economic development, government revenue, food security and livelihoods; (2) planned adaptations are needed to improve the way that the 'vehicles' (fisheries and aquaculture activities), which deliver these benefits, are managed to reduce the threats and harness the opportunities expected to arise from climate change; and (3) the fish habitats and fish stocks that underpin these benefits are managed in ways that maximise their capacity for autonomous adaptation to the effects of climate change (**Figure 13.3**).

We also assume that adaptations will be designed and delivered in a way that is acceptable to those whom they are intended to benefit (Section 13.2.5). This important pre-requisite is expected to be relatively easy to achieve in many cases because the traditional ways that Pacific people use to respond to and cope with extreme events such as cyclones and droughts[10,59–62] should predispose them to embracing and implementing the recommended adaptations. However, improvements can be made to traditional ways of responding to extreme events, particularly by (1) increasing the participation of women in all aspects of planning and applying adaptations, and (2) ensuring that the people likely to be affected are involved in negotiations to select and implement adaptations, so that their rights are respected.

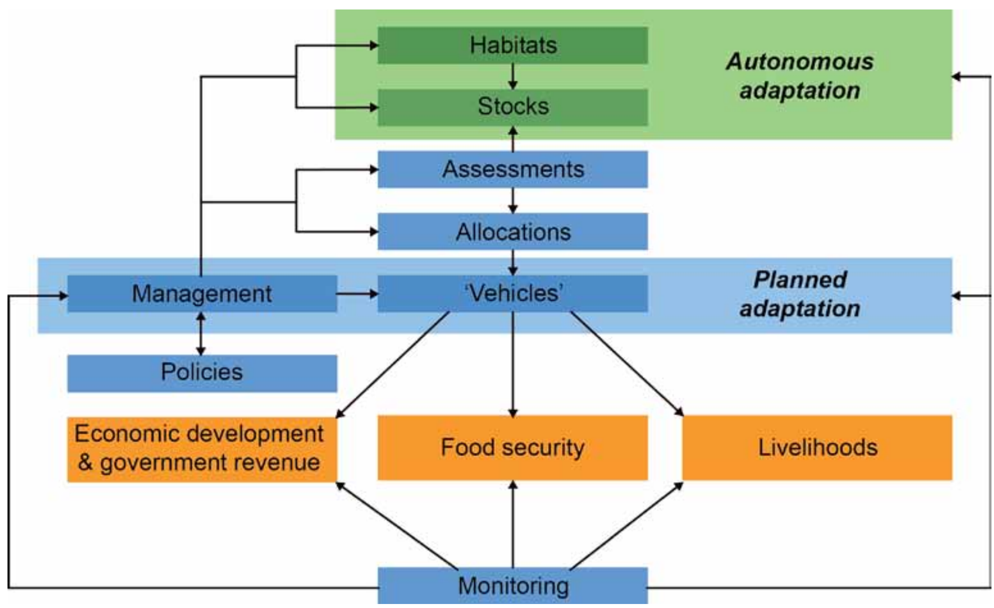

Figure 13.3 Relationships between the key objectives of fisheries management for Pacific Island countries and territories (orange), the resources on which these benefits are based (green), the actions and institutional outputs needed to deliver these benefits (blue), and the components of the system where autonomous adaptation could help limit the potential impact of climate change, and where planned adaptation should reduce the threats of climate change to economic development, government revenue, food security and livelihoods and capitalise on opportunities to increase these benefits.

Before introducing the adaptations and suggested policies, we briefly summarise the implications of climate change for the productivity of fisheries and aquaculture (Chapter 12) which these adaptations and policies are intended to address. The adaptations and suggested policies for economic development and government revenue, food security, and livelihoods are presented separately.

13.4.1 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 channelled 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 for the purse-seine fishery, which allocates fishing effort among the EEZs of the eight PNA countries based on agreed criteria[63,64], provides an important means of accommodating the effects of El Niño-Southern Oscillation (ENSO) events on redistribution 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)[65] 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[63,66,67]. 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 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[68], 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 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[69], 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[70]; and (2) replace steel cans with alternative forms of packaging[71], should also help maintain access to markets for tuna as global pressure to minimise the carbon footprint of fishing and processing operations increases.

Purse-seine vessel

Photo: Malo Hosken

➢ 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[72]. 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[73,74] 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 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.

13.4.2 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 13.4.1 are outlined below. The policies that apply to each adaptation are listed in **Table 13.2**.

- **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**[67] 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 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 13.9.2.2).

- **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[8].

- **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 13.2 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 13.4.1 and 13.4.2 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 13.4.2; W = win; L = lose.

13.4.3 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[1,75] (Chapter 1) centre on minimising the size of this gap through (1) appropriate management of coastal (and freshwater) fish habitats and stocks (Section 13.2); (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[76–80] and ecosystem-based fisheries management[81–83], and to address the effects of population growth on the availability of fish for food security[1,75].

The CEAFM co-management framework[32], 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.

13.4.3.1 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 13.4**). 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.

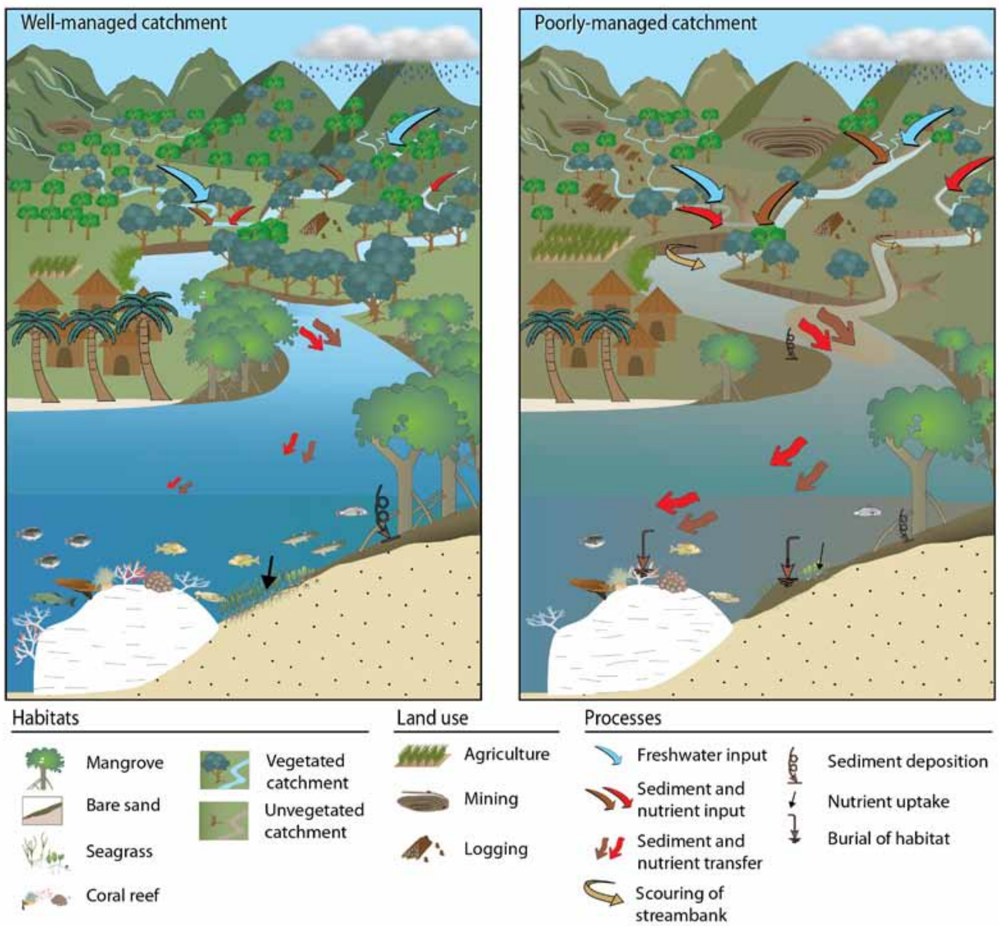

Figure 13.4 Differences in the quality of freshwater and coastal fish habitats under the influence of well-managed and poorly-managed catchments.

- 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[84,85].

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); and liaise 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 the adult demersal fish that dominate coastal fisheries (Chapters 6 and 9).

- Enlist the assistance of NGOs, coral reef task forces[x], and programmes such as Seagrass-Watch[xi] 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 nutrients 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 (**Figure 13.5**). 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.

x For example, the Coral Triangle Initiative (www.cti-secretariat.net/about-cti/plan-of-actions).

xi www.seagrasswatch.org/about.html

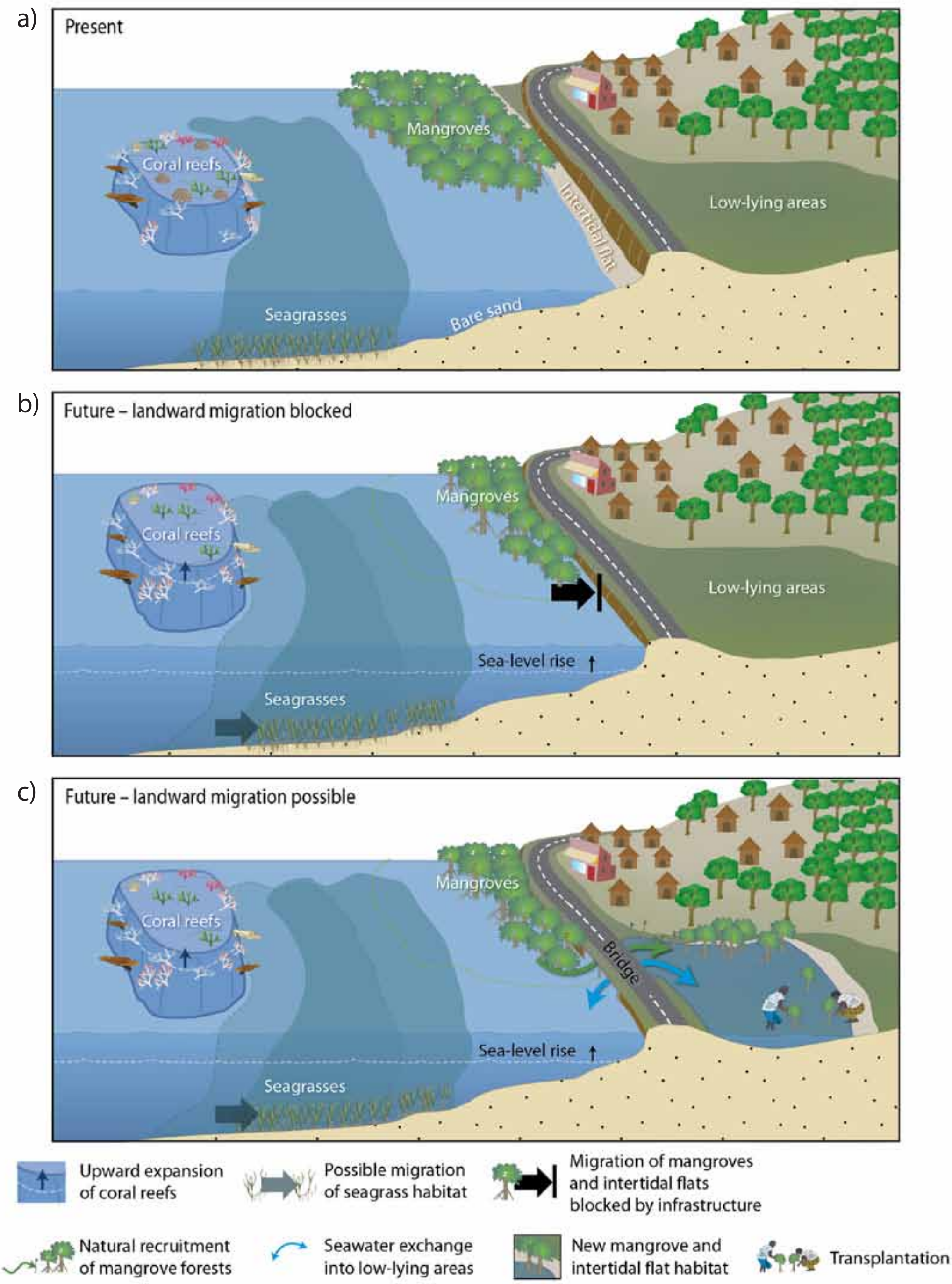

Figure 13.5 (a) Coral reef, mangrove, seagrass and intertidal habitats near low-lying undeveloped coastal land; (b) projected loss of mangrove and intertidal flat habitats because coastal infrastructure blocks their migration landward as sea level rises; and (c) modifications to road infrastructure to allow landward migration of mangroves and intertidal flat habitat, supplemented by mangrove replanting programmes.

- **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.

13.4.3.2 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 (Section 13.2.2) intended to keep production of demersal fish and invertebrates within sustainable bounds using a range of methods to assess data-poor fisheries[28,29,86,87]. 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[75] (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[29] (**Figure 13.1**). 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).

Fishing near a coral reef, Papua New Guinea

Photo: Jurgen Freund

➢ 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[88]; and (2) an increase in herbivorous species[89] 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 (Section 13.2.2), should help maximise the potential to realise gains from the increases of some fish species[90].

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[91,92]. 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 (Section 13.2.3) 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[93] (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.

13.4.3.3 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, now retained by industrial vessels transhipping their catch through capital cities in PNA countries, or landing it at other ports elsewhere in the region, 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[94,95]. 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)[96] (**Figure 13.6**) 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[96]. However, many communities will need training in the methods used to fish around FADs[97], 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)

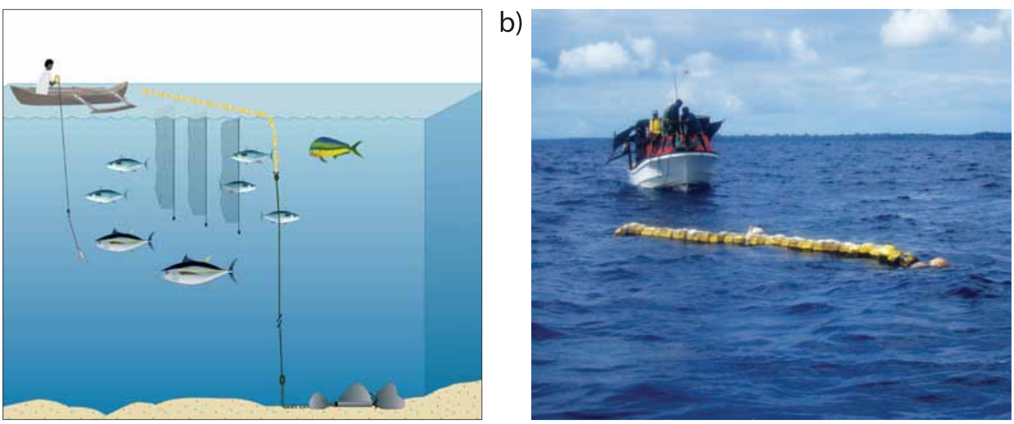

Figure 13.6 (a) Design of anchored, low-cost fish aggregating devices (FADs) suitable for placing in coastal waters (usually 300–1000 m deep) to increase access to skipjack and yellowfin tuna, and other large pelagic fish species; (b) surface buoys of a FAD in Papua New Guinea (photo: William Sokimi).

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 efficient 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 13.7**) in peri-urban areas, and for the benefit of inland communities in PNG[98] 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[99,100], where much of the production is based on Nile tilapia *Oreochromis niloticus*, including genetically improved, farmed tilapia (GIFT) varieties[101]. Nile tilapia are easy to reproduce and usually reach harvest size within 4–6 months in the tropics[102,103]. Carp and milkfish also have potential for pond aquaculture (Chapter 11).

a) b)

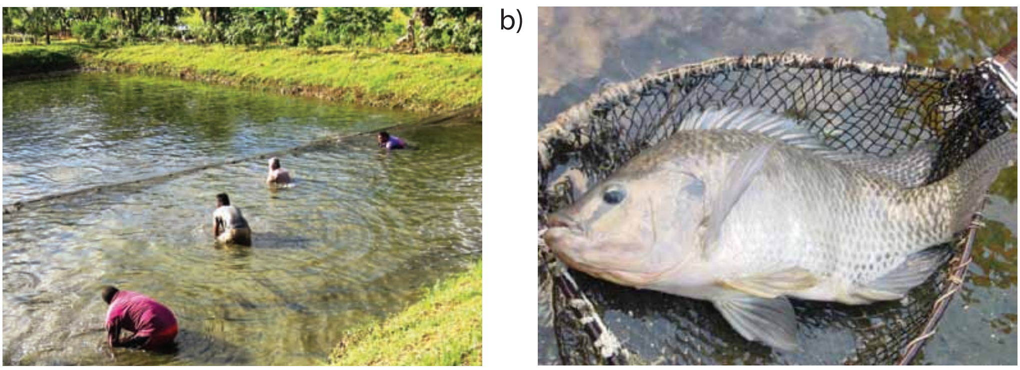

Figure 13.7 (a) Harvesting Nile tilapia from a freshwater pond in Fiji; and (b) a farmed Nile tilapia (photos: Timothy Pickering).

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.

➢ 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

A school of small pelagic fish – mackerel *Rastrelliger brachysoma*

Photo: Nathalie Behring

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[104]. 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.

13.4.4 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 13.4.3 are outlined below. **Table 13.3** 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**[105,106] by zoning pond aquaculture. Until the research recommended (Section 13.9.1.4) 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 13.3 Summary of adaptations and companion supporting policies to maintain the contributions of fish to food security for Pacific Island countries and territories (see Sections 13.4.3 and 13.4.4 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 13.4.4; W = win; L = lose.

13.4.5 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 Sections 13.4.1–13.4.4. 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 13.4.3) 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.

Smoking fish, Kiribati

Photo: Jocelyn Carlin

➢ **Adaptation L2: Rebuild populations of sea cucumbers and trochus (lose-win)**

Primary fisheries management (Section 13.2.2) 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[87]. 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 13.4.3).

➢ **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.

13.4.6 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 13.4.5 are outlined below. The policies that apply to each adaptation are listed in **Table 13.4**.

- **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 13.4 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 13.4.5 and 13.4.6 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 13.4.6; W = win; L = lose.

13.5 Interactions among adaptations

The adaptations recommended above have been designed to fit into existing management frameworks to address the effects of population growth and habitat degradation in the short term, and climate change in the long term (Sections 13.2–13.4). However, stakeholders need to know (1) whether they are likely to succeed in the context of other processes involved in the use of resources; and (2) whether any negative interactions among these adaptations could occur. Also, some adaptations, or combinations of adaptations, may be more effective than others. Qualitative models[107,108] (Appendix 13.1) can help to answer these questions.

To demonstrate the usefulness of these tools, we have used a qualitative model to examine the relationships between the key adaptations recommended to maintain the role of fish in providing food security for coastal communities. The model considered the effects of (1) longstanding relationships among fishing effort, stocks of demersal fish and inshore pelagic fish, catch, markets and food security; (2) human population growth and habitat degradation as drivers of these relationships; (3) practical adaptations to maintain access to adequate fish for food security in the face of these drivers; and (4) the possible impact of climate change on these adaptations.

The qualitative model (**Figure 13.8**) shows the effects of subsistence and artisanal fisheries on the stocks of demersal and nearshore pelagic fish through the variables of fishing effort, catch and the market value of catch[107]. Food security is dependent on catch, which is determined by both fishing effort and stock abundance, and which suppresses the market value of the proportion of the catch sold via a supply-demand relationship. Fishing effort increases catch and reduces stock abundance, although the effect of coastal fishing on stocks of tuna is negligible compared with the effect of industrial fleets (Chapters 8 and 9) and has been omitted from the analysis. The benefits of catch support fishing effort and food security. The key drivers – human population growth and habitat degradation – shape the system in positive and negative ways. An increasing human population creates greater demand for food, leading to increased fishing effort. Population growth also contributes to degradation of the coral reefs, mangroves and seagrasses that support demersal fish stocks. Planned adaptations to maintain or increase access to fish for food security include integrated coastal zone management, management to rebuild demersal fish stocks, the use of inshore FADs to increase the catch of nearshore pelagic fish, pond aquaculture and post-harvest processing (Section 13.4).

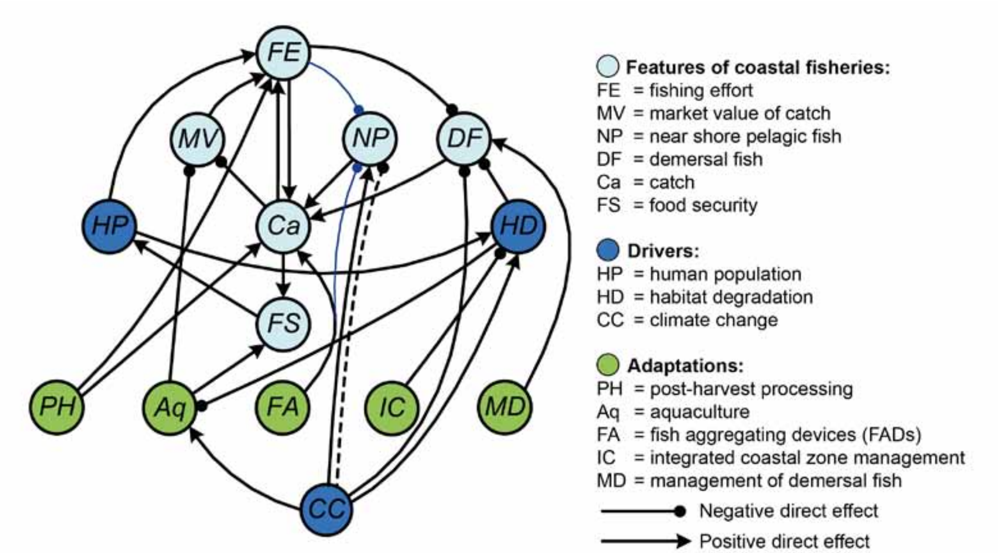

Figure 13.8 Signed digraph model of factors affecting the use of fish for food security by coastal communities in Pacific Island countries and territories under the A2 emissions scenario. Light blue circles represent major variables regulating delivery of protein from coastal fisheries; dark blue circles represent some important drivers in the system, and green circles represent possible key adaptations for food security. Links ending in an arrow represent positive direct effects and links ending in a filled circle represent negative direct effects. In 2035, the effects of climate change on catches of nearshore pelagic fish are projected to be positive across the region, but are expected to be negative in the western Pacific by 2100 (as denoted by the dashed line). The two thin-blue lined links indicate that fishing effort has a negligible effect on the tuna stocks that comprise much of the nearshore pelagic fishery. Note that in model analyses each variable was given a negative self effect (see Appendix 13.3 for further details).

The effects of climate change on the various relationships within the model are expected to:

- decrease reproduction and recruitment of demersal fish resulting from the direct effects of increased SST and ocean acidification, and the indirect effects of degradation of coral reefs, mangroves and seagrasses, exacerbated by poor coastal development (Chapters 5, 6 and 9);
- increase the abundance of nearshore pelagic fish (tuna) throughout the tropical Pacific in 2035, reduce stocks of these fish in the west by 2100, and increase them in the east until at least 2100 (Chapter 8); and

- augment aquaculture production through expansion of freshwater fish farming (Chapter 11).

The perturbations to the model (human population growth, habitat degradation and climate change) were applied differently for the eastern and western Pacific in 2035 and 2100 because human populations are predicted to increase substantially only in the west (Chapters 1 and 12), and climate change is projected to have different effects on nearshore pelagic fish in these two parts of the region (Chapter 8).

The total number of positive and negative effects on food security generated from the perturbations due to population growth and habitat degradation indicate that:

1. the contribution of catch to food security in the western Pacific is generally likely to be lower than in the eastern Pacific, demonstrating the overriding influence of increased human populations in the system – larger numbers of people have a powerful effect on reducing the fish available per person;
2. there are no adverse or unintended consequences for food security in any combination of the adaptations;
3. more adaptations result in better outcomes for food security; and
4. integrated coastal zone management, and the use of FADs combined with post-harvest processing, have the greatest positive effect on food security.

Adding climate change as another perturbation does not change the generality of these conclusions, but the projected changes in climate make it harder for these adaptations to achieve their goals in 2035, and progressively more difficult by 2100. The adaptations are also more effective in the eastern than in the western part of the region, because there is not the added pressure of large increases in human population in the east.

The qualitative nature of the model does not allow for the importance of the various adaptations to be considered precisely. This weakness is balanced, however, by the ability of qualitative models to identify variables or links that merit more in-depth investigation through other modelling approaches[108]. For example, FADs promise to provide much greater access to fish for food than aquaculture (Chapter 12). Models that weight the relative importance of these two adaptations appropriately will provide a clearer picture of their potential to enhance food security.

13.6 Planning needed to implement key adaptations

Although the technology underpinning many of the adaptations recommended here is mature, the proposed interventions will not work in all PICTs, or in all locations within a country. Additional planning will be needed to identify sites with the appropriate biological and socio-economic conditions. The use of inshore, anchored

FADs and pond aquaculture to diversify access to fish for food security are prime examples. In the case of FADs, information is needed from local communities to identify inshore areas frequented by tuna, and to identify which parts of these areas have suitable depths and bathymetry for deploying FADs to attract and temporarily hold tuna (**Figure 13.9**). Such information can be used to identify where FADs can be installed so that coastal communities can reach them easily using canoes or motor boats.

Spatial satellite imagery can also be used to identify which coastal and inland villages are close to suitable sites for pond aquaculture. Availability of flowing fresh water is not the only factor that must be considered when planning the development of pond aquaculture, however. Geographic information system (GIS) analysis of soil type, slope, rainfall and forest cover is also needed to select areas where environmental conditions are likely to be generally suitable for construction and operation of ponds[109]. At the national level, GIS analysis of population density and alternative livelihood options also needs to be considered when deciding where to encourage investors to build hatcheries to supply the juvenile fish needed by farmers. Such planning is already underway for Fiji (**Figure 13.10**).

An advantage of identifying where FADs and pond aquaculture have the potential to diversify access to fish is that the information can be combined with the area of coral reef per person for a village, to determine the extent to which these key adaptations are likely to increase local supplies of fish. Coastal communities are expected to fall into one of seven broad vulnerability categories with respect to shortages of fish, based on availability of demersal fish, and the potential to deploy FADs and build fish ponds (**Table 13.5**).

Table 13.5 Broad categories of vulnerability of coastal communities to future shortages of fish, depending on area of coral reef per person, and opportunities to install inshore fish aggregating devices (FADs) and develop pond aquaculture.

Attributes of coastal and inshore environment			Vulnerability
Coastal fisheries expected to meet future demand*	Areas suitable for FADs	Areas suitable for pond aquaculture	
Yes			Very low
No	Yes[a]	Yes	Very low – low
No	Yes[b]	Yes	Low
No	Yes[a]	No	Low – medium
No	Yes[b]	No	Medium
No	No	Yes	High
No	No	No	Very high

* Based on area of coral reef per person; a = FADs anchored in depths < 500 m and within paddling distance by canoe, i.e. within 1 km of the coast; b = boat and motor needed to reach FADs anchored in depths of up to 1000 m within 6 km of the coast.

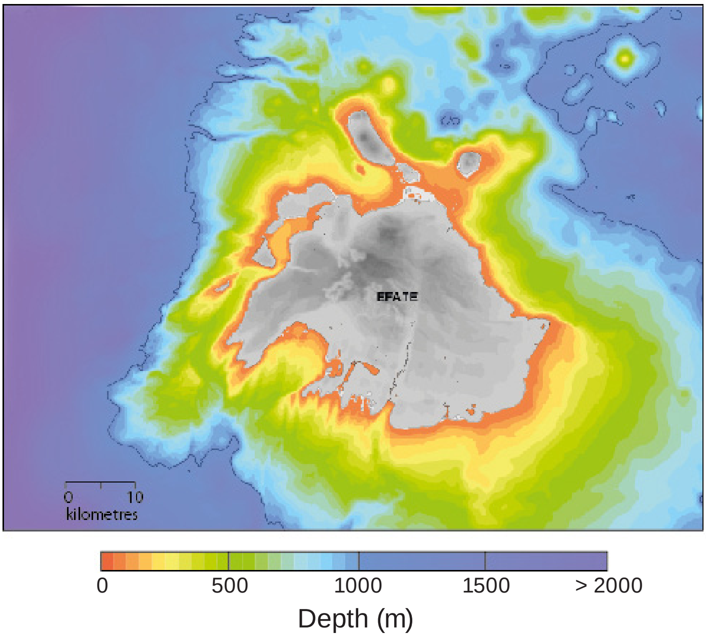

Figure 13.9 Bathymetric map of Efate Island, Vanuatu. Fish aggregating devices (FADs) could be anchored in depths of 300–1000 m to increase access to tuna for both subsistence and small-scale commercial fishers (source: Kruger et al. 2007)[123].

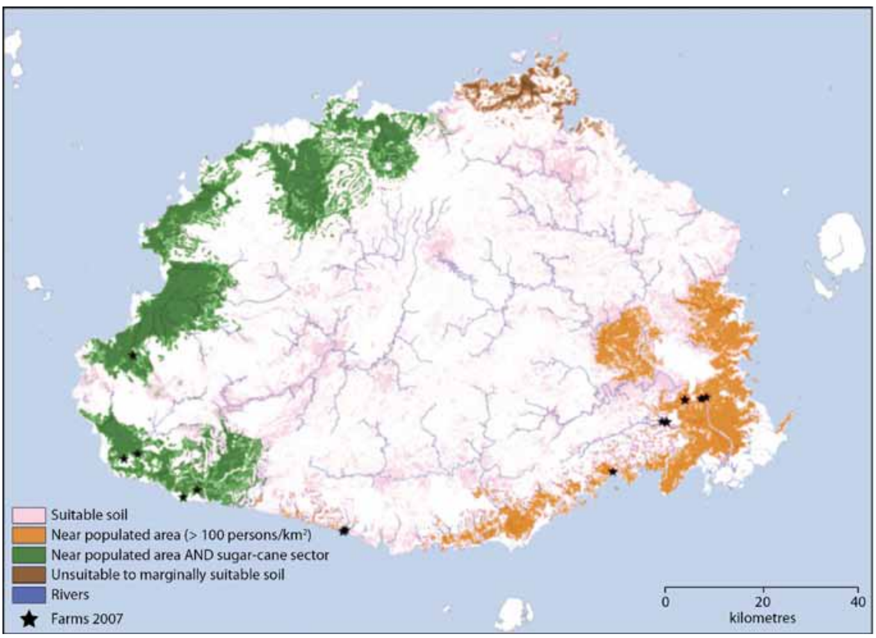

Figure 13.10 Map of Viti Levu Island, Fiji, showing areas with soils suitable for aquaculture ponds, the areas of greatest population, the location of sugar cane farming, the freshwater rivers and the locations of existing ponds for Nile tilapia. This information can be used to inform decisions about where to locate additional ponds and the hatcheries needed to supply juvenile fish (source: Chagnaud 2008)[109].

Understanding where and how the vulnerability of coastal communities to shortages of fish can be reduced by diversifying production will not only help build resilience to climate change, it could also help communities cope with non-climate related disasters, such as tsunamis. Where diversifying access to fish is not possible, communities and governments will need to place more emphasis on other ways of providing access to food and opportunities to earn income[41], for example, development of 'climate ready' crops[6,84].

13.7 The need for monitoring

The adaptations described in Section 13.4 are designed to increase the flexibility of industrial fisheries and communities to deal with projected changes in fisheries resources. However, the uncertainties associated with the projections made in Chapters 2–11 could result in other outcomes. Unexpected outcomes are likely to need alternative or modified adaptations.

To ensure that the most appropriate adaptations are applied at the right times and in the right places, PICTs will need to monitor whether changes to fish habitats and fisheries resources occur at the projected rate. Practical, well-designed programmes which can be implemented effectively by PICTs and regional organisations are required to regularly assess the status of fisheries resources and the ecosystems that support them. Monitoring is also needed to measure the success of adaptations.

The systems in place to assess variation in the distribution and abundance of tuna allow managers to monitor the effects of fishing and climate change on stocks (Chapter 8). Such monitoring is not in place for coastal fisheries in most PICTs, however, where even the basic information required to apply primary fisheries management is often missing. The three broad categories of monitoring needed for coastal fisheries are described below.

1. Assessments of the species composition and size structure of catches to provide baselines and reference points for management, against which change can be measured. This will require sampling of coastal fish catches at central markets in ways where the data can be recorded, stored and analysed easily by PICTs. Systems based on digital photography and image analysis should simplify this process.
2. Sampling to separate the effects of climate change and other stressors on coastal fish habitats, and on stocks of demersal fish and invertebrates. This will require comparisons between degraded/fished and healthy/unfished areas at representative PICTs across the region. For fish habitats, simple methods for collecting remotely-sensed data, and ground-truthing this information, have a role to play, although measures of changes in coral species composition and topographic complexity will also be needed because of their importance in

determining the abundance of demersal fish. For fisheries resources, simple indicators of abundance and size structure, which can be collected consistently by diver census over the long term, will be required.

3. Measures to assess the success of adaptations designed to maintain the benefits of fisheries and aquaculture for economic development, government revenue, food security and livelihoods. National accounts, censuses and household income and expenditure surveys (HIES) all have potential to provide the necessary data[110,111]. Assessing the success of adaptations for food security and livelihoods will also involve measuring success against a social baseline founded on human development indicators[112]. Such baselines still need to be established for many PICTs.

The imperative is to develop the necessary monitoring tools and implement long-term national and regional monitoring programmes as soon as possible – the longer the time-series, the greater the power to detect change and provide the information needed for adaptive management.

It is unlikely that the effects of climate change on aquaculture can be separated from other drivers by sampling programmes. However, there is much scope to improve the quality of production data required to measure the success of adaptations and policies in the aquaculture sector. A uniform system is needed for PICTs to record key information, such as the quantities or volumes of commodities produced for commercial sale or subsistence, number of farm units, number and gender-balance of people employed part- and full-time, and export value. This system should be designed to make it easier for countries to provide the information required by the Food and Agriculture Organization of the United Nations (FAO) for their regular 'State of World Fisheries and Aquaculture' reports.

13.8 Gaps in knowledge

Although the vulnerability assessments for fish habitats, fish stocks, and the national economies, industries and communities that rely on these resources (Chapters 4–12) were based on the best information available – the suite of global climate models from the Coupled Model Intercomparison Project, Phase 3 (CMIP3) used for the Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC-AR4) – much uncertainty still surrounds these assessments. This uncertainty is due to (1) the coarse grid sizes of the CMIP3 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 invertebrates.

Here, we summarise the information needed to fill these gaps. We also consider the research needed to determine how Pacific communities are likely to accept and implement the recommended adaptations.

13.8.1 Knowledge needed to improve the understanding of vulnerability

13.8.1.1 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.

Photo: Franck Magron

Weather is an important consideration for coastal fishers

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[xii].

13.8.1.2 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[20,113].
- 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.

xii www.cawcr.gov.au/projects/PCCSP

Coral reefs

To reduce the uncertainty about how emissions of CO_2 and other greenhouse gases are likely to affect coral reefs, 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.

13.8.1.3 Fish stocks

Oceanic fisheries

In addition to the need to downscale global climate models (Section 13.8.1.1), and parameterise biogeochemical models with better information on nutrients, iron and micronekton (Section 13.8.1.2), 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 13.8.1.2).
- 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.

Tropical snappers, an important part of the coastal fish catch

Photo: SPC collection

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.

13.8.1.4 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 GIS data (Section 13.6) 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.

13.8.2 Knowledge needed to implement adaptations effectively

13.8.2.1 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 13.4), 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 analysis encompasses the effects of population growth on local demand for fish, and the effects of climate change on the projected availability of tuna, it should aid PICTs to optimise future benefits from their tuna resources, and 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 other opportunities for people to earn income.

13.8.2.2 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.

13.9 Investments required

To maintain the important contributions of fisheries and aquaculture to the region, investments by PICTs and their development partners are required at several levels. In particular, investments are needed to:

1. launch the adaptations (Section 13.4) that PICTs see as priorities for economic growth, government revenue, food security and livelihoods to address the threats and opportunities associated with climate change, and to accommodate other drivers (Section 13.3);
2. fill the gaps in knowledge required to improve our understanding of vulnerability;
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.

Because this vulnerability assessment has been designed to provide guidance mainly at the national level, investments are also needed to 'localise' the results to assist communities to evaluate their vulnerability and adapt accordingly.

Photo: Jack Fields

A community fishing over sand flats, French Polynesia

13.9.1 Investments to implement adaptations

The adaptations recommended in Section 13.4 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.

13.9.1.1 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 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.

13.9.1.2 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[xiii].
- 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

xiii Pacific Islands Forum Secretariat, Forum Communiques; www.forumsec.org.fj/pages.cfm/documents/forum-communiques 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.

Photo: Christine Fung

Preventing soil loss by replanting grass, Fiji

- 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 (Section 13.2), 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.

- 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.

13.9.1.3 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.

13.9.2 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.

13.9.2.1 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.

13.9.2.2 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[xiv];
- 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[xv];
- 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, to inform regional and national management agencies. An example of the finer spatial scale projections expected to be possible with SEAPODYM using information from downscaled physical models of the tropical Pacific Ocean and improved biogeochemical models is shown in **Figure 13.11**.

13.9.2.3 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.

xiv www.argo.ucsd.edu

xv See www.imber.info/CLIOTOP_MAAS.html for more details.

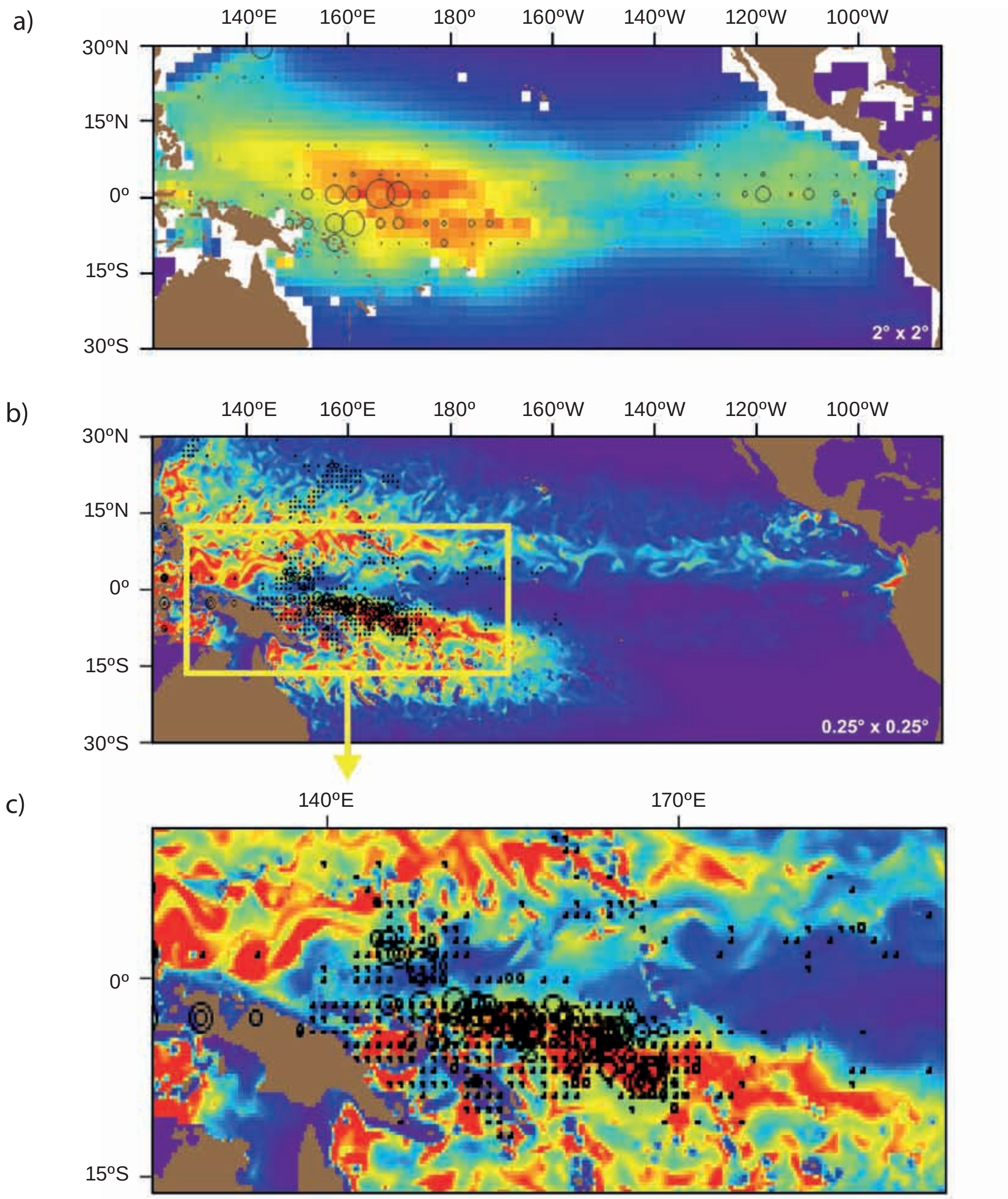

Figure 13.11 Simulations of skipjack tuna distributions in the tropical Pacific Ocean produced by the SEAPODYM model using different resolutions of environmental forcing and fisheries/ecosystem data: (a) average for the period 1980–2007 using environmental forcing at resolutions of 2 x 2 degrees, and fisheries data at a resolution of 1 x 1 degree or lower, and a monthly time interval; (b) average for the period 1998–2007 using environmental forcing and fisheries data at a resolution of 0.25 degree or lower plus primary production estimates from satellite data; and (c) an example of a weekly time interval from the period in (b). Circles indicate relative abundance of skipjack tuna (source: Patrick Lehodey).

- 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.

13.9.2.4 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.

13.9.2.5 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).

13.9.3 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 13.4; (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 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)[xvi] should also be considered to ensure that lessons learned from other regions can be passed on to PICTs, and vice versa.

13.9.4 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.

xvi 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 HIES 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.

13.9.5 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[29,114] based on the information in 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.

Photo: Jack Fields

Women fishing in Fiji

13.10 Considerations for financing adaptations

PICTs will need to devote substantial resources to evaluate and implement the priority adaptations for the fisheries and aquaculture sector. Investments for many of the win-win adaptations outlined in Section 13.4 need to be made now, whereas others may not be required for several decades. As well as identifying when to make these investments, it is essential that PICTs understand (1) the relative costs and benefits of recommended adaptations, including their sustainability and social acceptability; and (2) the opportunity costs of investments relative to other development needs and priorities.

It is widely recognised that PICTs require substantial financial assistance to make the necessary investments. Bilateral and multilateral funding for adaptation of PICTs has already been provided by Australia, EU, France, Germany and USA, and the Asian Development Bank and the World Bank. The broader international community is also planning to provide significant funds during the coming decades to meet the costs of adaptation in developing countries through the United Nations Framework Convention on Climate Change (UNFCCC). Several funding opportunities are offered under the Convention, including the Adaptation Fund, the Global Environment Facility, and the Least Developed Countries Fund[xvii]. The Pacific Islands Forum Secretariat is presently evaluating options for PICTs to receive their share of this longer-term climate change financing, including the possible establishment of a dedicated Pacific climate change finance mechanism.

In collaboration with their technical partners, PICTs will need to develop a strong business case for adaptation financing at community, national and regional levels. The key activities involved in making this case are listed below.

- Build the capacity of fisheries departments and managers, and national planning officials, to explore the implications of climate change for the contributions of fisheries and aquaculture to economic development, government revenue, food security and livelihoods.
- Identify the magnitude and timing of the effects of climate change on the fisheries and aquaculture sector, and the appropriate adaptations to reduce the threats and capitalise on the opportunities.
- Develop action plans that clearly identify the costs, benefits and implementation timelines for priority adaptations, including fully-costed proposals for submission to bilateral, regional and multilateral financing programmes.
- Work with technical agencies and community groups to enable priority adaptations for the fisheries and aquaculture sector to be evaluated against other adaptation financing needs, taking into account the likely total financing opportunities available from international sources.

xvii www.unfccc.int/adaptation/implementing_adaptation/adaptation_funding_interface/items/4638.php

- Develop and implement appropriate monitoring and evaluation mechanisms, so that the success of adaptation responses can be estimated to identify their strengths and weaknesses, and refined to deliver optimal benefits.

The information presented in this book, and the companion 'Summary for Pacific Island countries and territories'[115] is intended to facilitate this task.

13.11 Concluding remarks

This book sets out the sequence of projected changes to surface climate and the tropical Pacific Ocean under the B1 and A2 emissions scenarios in 2035 and 2100 (and A2 in 2050[xviii]), to fish habitats and fish stocks and, ultimately, to the contributions of fisheries and aquaculture to the economic development and government revenue of PICTs, national food security, and livelihood opportunities (Chapters 2–11). Contrary to assessments for some other parts of the world[8,88,116,117], the implications of the projected changes are not all negative.

The deleterious effects for Pacific communities are expected to be greatest for demersal coastal fisheries, where production is projected to decrease by 20% in 2050 and by 20–50% in 2100 under the A2 emissions scenario. This decrease is due to the direct effects of climate change on demersal fish, and the indirect effects of declines in the coral reef, mangrove, seagrass and intertidal flat habitats that support these species due to global warming and ocean acidification (Chapters 5, 6 and 9). However, notwithstanding the need to manage catchments and coastal fish habitats and stocks to secure reliable levels of fish production, coastal communities also have the option of switching some fishing effort from demersal fish to the tuna that often frequent coastal waters. This can be done by developing the nearshore fishery for these large pelagic species, and by installing anchored FADs close to shore to attract and temporarily hold these species (Section 13.4).

The rich tuna resources of the Western and Central Pacific Ocean can also be used to provide increased access to fish for the rapidly growing urban populations of the region, supplemented by the development of peri-urban pond aquaculture. More emphasis on the management of freshwater fisheries and development of pond aquaculture where conditions are suitable also promises to provide improved access to fish in inland areas.

The assessments in this book indicate that adaptations based on increased access to tuna are likely to be favoured by climate change until 2035 for all PICTs, and for the eastern part of the region until at least 2100. Production from freshwater fisheries and pond aquaculture is also expected to increase throughout much of Melanesia because the projected increases in rainfall and temperature are likely to enhance yields of the key species.

xviiiBased on the simulations for B1 in 2100.

The key challenges for the region are to:

1. reduce the effects of local stressors on fish habitats by legislating to restore and protect catchment vegetation and prevent direct damage to coral reefs, mangroves, seagrasses and intertidal flats, caused by excess sediments, nutrients, pollution and poor management of waste;
2. launch win-win adaptations to address the imminent reductions in the fish available per person for good nutrition, due to predicted population growth in many PICTs (Chapter 12), in ways that should be favoured by climate change;
3. create flexible policy arrangements to ensure continued supplies of fish to the established and proposed processing facilities in the region as the distribution of tuna shifts to the east; and
4. manage coastal aquaculture enterprises producing commodities for export and local markets to optimise employment opportunities in the face of increasingly adverse conditions due to climate change and ocean acidification.

Meeting these challenges by implementing the adaptations presented here, and the suggested policies and investments needed to support them, will also address other pressures that face the sector. Some longstanding problems caused by these pressures need immediate attention, for example, integrated coastal zone management to protect fish habitats (Chapters 5–7), restoration of sea cucumber fisheries (Chapter 9) and providing better access to tuna for food security (Chapter 12). Investments in both the win-win and lose-win adaptations described in Section 13.4 designed to address these problems have the added benefit of making natural resources, communities and economies more resilient to the effects of the changing climate. Such investments are priorities for the fisheries and aquaculture sector of PICTs across the region.

Nevertheless, the recommended adaptations resulting from this vulnerability assessment are not definitive. Uncertainty remains about the magnitude of the projected effects of climate change on the sector due to the coarse resolution of the CMIP3 global climate models used to determine changes to surface climate, the tropical Pacific Ocean, and tuna stocks (Chapters 2–4 and 8). Some of this uncertainty will be reduced through the development of downscaled models by Australia's Pacific Climate Change Science Programme, and related initiatives. The investments in modelling and monitoring proposed in Sections 13.5 and 13.7 should also allow PICTs and their technical partner agencies to (1) examine interactions and synergies among potential adaptation options; (2) track changes in the habitats and stocks that underpin oceanic, coastal and freshwater fisheries, and aquaculture, and (3) measure the success of selected adaptations.

We recommend that the technical agencies supporting PICTs adopt a process similar to that used by the IPCC for its assessment reports to regularly evaluate (1) the effects of climate change on the region's vital fisheries and aquaculture resources, and

(2) the plans to use these resources sustainably for economic development, government revenue, food security and livelihoods. In particular, the 'Summary for Pacific Island countries and territories' accompanying this book should be updated every 5–7 years with the latest projected changes to surface climate, the tropical Pacific Ocean, fish habitats and fish stocks. Updating this vulnerability assessment on a regular basis will allow the main economic and social implications to be understood more clearly, and the key adaptations required to maintain benefits from the sector to be adjusted accordingly.

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Appendix 13.1 Overview of qualitative modelling

Qualitative modelling[107,124–129] describes the relationships linking variables within a system, and the implications of these links to the feedback properties and dynamics of the whole system. Qualitative models use the sign (i.e. positive, negative, zero) for direct effects between variables, which are depicted as links in a signed-directed graph (**Figure 1**). A link ending in an arrow represents a positive direct effect of one variable on another, and one ending in a filled circle indicates a negative direct effect. All possible pairwise ecological relationships can thus be represented as: predator-prey (+,-), competition (-,-), mutualism (+,+), commensalism (+,0), and amensalism (-,0). Signed digraphs can also be used to describe various kinds of relationships, for example, the two variable systems in **Figure 1a** can be used to represent an ecological predator-prey relationship, or an economic supply-demand relationship. Links leading from a variable to itself denote self-effects. Processes that lead to self regulation, such as a density-dependent rate of reproduction in a population, confer a negative self effect, whereas self-enhancing processes create positive self effects. If the growth of a variable is determined solely from the other variables included in the model, then it will possess no self effect.

Qualitative models can also depict interactions that are enhanced or suppressed by another variable. For example, **Figure 1c** shows how variable Z acts to increase the intensity of the predator-prey interaction of X and Y, which is indicated by a dash-lined positive link. This modified interaction results in direct effects leading from Z to variables X and Y, the sign and direction of which is determined by the product of the dashed-lined link and the individual pairwise links. In this example, the product of the positive dashed-lined link from Z and the negative link leading to X creates a negative link leading from Z to X.

Tracing the cyclical pathway of links in a system defines its feedback cycles, and analysis of these cycles is used to determine the stability of the system. The model system in **Figure 1a** has two negative feedback cycles. One cycle of length one is from the self effect of variable X, while a feedback cycle of length two is defined from the product of the positive and negative links connecting X and Y. This system has only negative feedback, and thus an increase in X leads to an increase in Y, which then acts to limit X. This negative feedback guarantees that the system has the ability to recover from a disturbance through self correction. **Figure 1b** presents an example of a model system with a positive feedback cycle involving three variables. Here an increase in population diminishes available resources. This lack of resources creates an incentive for development of additional resources, which thereby supports further increase in population, i.e. when available resources are plentiful there is little incentive to develop new resources, but when availability is limited there is increased effort to secure new resources; this dynamic creates a negative link from variable Z to Y in the model of **Figure 1b**. Such a positive feedback, if not counterbalanced by the three negative self effects, can continually drive the system and prevent it from reaching equilibrium.

Where a variable is the point of input to the system, the response of the other variables can be determined from the product of the links along direct and indirect pathways emanating from that variable. For example, an input that acts to increase Z in **Figure 1c** will cause X to decrease by two negatively signed pathways, i.e. a direct negative effect from Z and an indirect negative effect via Y. The response of variable Y to this input, however, is qualitatively ambiguous, as there is both a positively and negatively signed pathway leading to Y from Z. This ambiguity can be resolved through knowledge of the relative strengths of the links involved. In larger and more complicated systems, however, there can be a vast number of oppositely signed pathways and interpreting the ambiguity through the relative strength of links is impossible. In such cases, a probabilistic interpretation of the number of positively and negatively signed pathways is used to predict the likely sign of a variable's response.

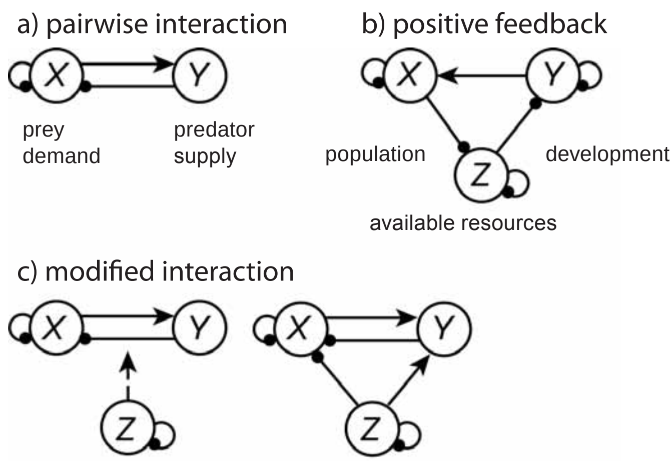

Figure 1 Examples of signed digraphs showing model systems with (a) two variables with negative feedback between them; (b) three variables with positive feedback; and (c) a system where one variable modifies the intensity of the interaction of two other variables; see text for further explanation.