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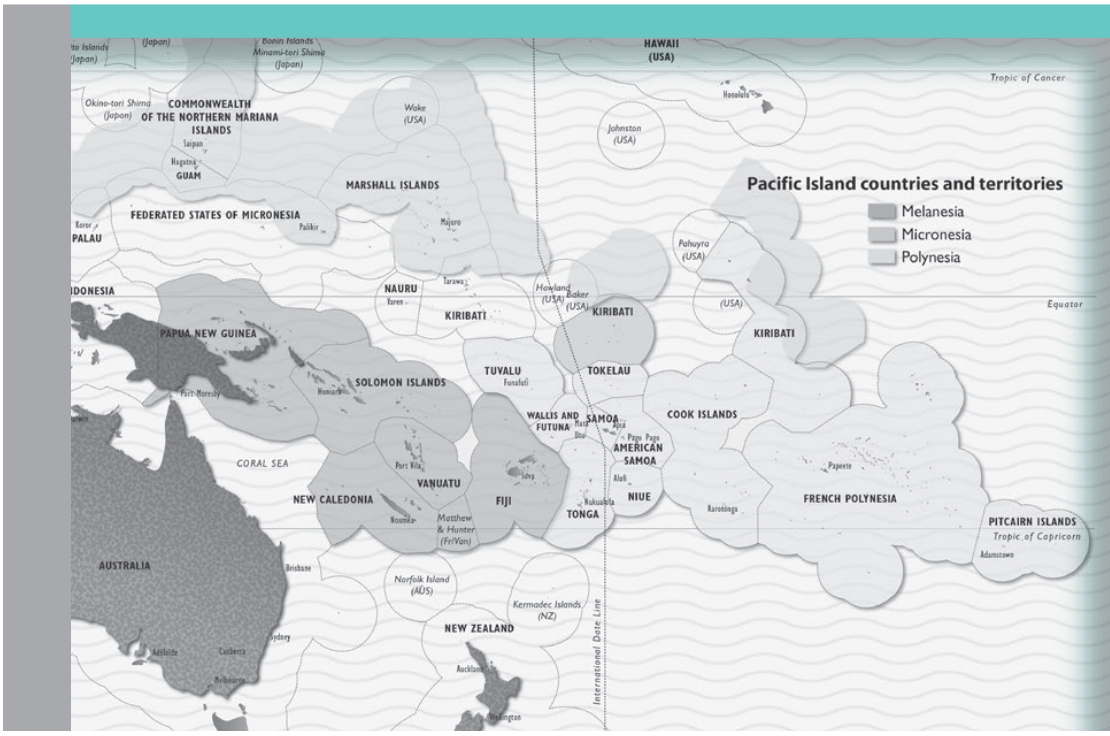
Priority adaptations to climate change for Pacific fisheries and aquaculture

Reducing risks and capitalizing on opportunities

FAO/Secretariat of the Pacific Community
5–8 June 2012
Noumea, New Caledonia



SPC Secretariat of the Pacific Community

FAO FIAT PANIS

Cover map: This map is indicative only of agreed and potential maritime boundaries between Pacific Island countries and territories (PICTs). It does not reflect the claims of PICTs to offshore areas.
Courtesy: Bell *et al.* 2011b.

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These Proceedings present the outcome of the Workshop "Priority adaptations to climate change for Pacific fisheries and aquaculture: reducing risks and capitalizing on opportunities". The Workshop was hosted by the Secretariat of the Pacific Community (SPC) in Noumea, New Caledonia, from 5 to 8 June 2012. It was a special workshop for the SPC Heads of Fisheries jointly organized by FAO and the SPC and financed by support from AusAID and the Governments of New Caledonia, Japan and Sweden.

The contributed paper is reproduced as submitted.

Abstract

This publication includes: (i) a summary of the technical presentations provided to the Workshop participants on the implications of climate change for Pacific fisheries and aquaculture; and (ii) the outcomes of discussions by participants on the priority adaptations that Pacific island countries and territories (PICTs) can implement to reduce risks and take advantage of opportunities. The Workshop was hosted by the Secretariat of the Pacific Community (SPC) as the culmination of 3.5 years of work to assess the vulnerability of Pacific fisheries and aquaculture to climate change. It also formed part of a series of climate change awareness-raising and adaptation planning workshops around the globe financed through a Japanese-funded, and FAO-implemented, project "Climate Change, Fisheries and Aquaculture: Understanding the Consequences as a Basis for Planning and Implementing Suitable Responses and Adaptation Strategies" (GCP/INT/253/JPN). The technical presentations and range of possible adaptations and supporting policies presented were based on SPC publications. Discussions focused on priority adaptations for economic development and government revenue, food security and sustainable livelihoods for Melanesian, Micronesian and Polynesian nations. The adaptations identified reflect the different fisheries participation rates and importance of fish to economic development and as a source of local food and income in these different regions. The Workshop discussions recommended immediate action by all PICTs to manage fisheries resources sustainably now and into the future, to establish systems to minimize impacts of various drivers facing the sector now and from future climate change, and to capitalize on opportunities. Cooperation between PICTs and partnerships among governments, regional and international organizations and communities were highlighted as important ways to implement effective adaptation.

Johnson, J., Bell, J. & De Young, C. 2013.
Priority adaptations to climate change for Pacific fisheries and aquaculture: reducing risks and capitalizing on opportunities.
FAO/Secretariat of the Pacific Community Workshop, 5–8 June 2012, Noumea, New Caledonia.
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Acknowledgements

The Secretariat of the Pacific Community (SPC) is thanked for hosting the Workshop and providing technical and administrative support. The invaluable contribution of the Workshop participants and the technical experts who contributed to the SPC vulnerability assessment is greatly acknowledged.

Abbreviations and acronyms

ADB	Asian Development Bank
AusAID	Australian Agency for International Development
CI	Conservation International
Code	Code of Conduct for Responsible Fisheries
DRM	disaster risk management
EAF/A	ecosystem approach to fisheries/aquaculture
EEZ	exclusive economic zone
EIA	environmental impact assessment
ENSO	El Niño-Southern Oscillation
FAD	fish aggregating device
FAO	Food and Agriculture Organization of the United Nations
FFA	Forum Fisheries Agency
GDP	gross domestic product
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit, (German Society for International Cooperation)
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JNAP	joint national action plan
LDCF	Least Developed Countries Fund
LLMA	locally managed marine area
NAP	national adaptation plans
NAPA	national adaptation programme of action
NGO	non-governmental organization
PaCFA	Global Partnership on Climate, Fisheries and Aquaculture
PICTs	Pacific island countries and territories
PNA	Parties to the Nauru Agreement
SCCF	Special Climate Change Fund
SEAPODYM	Spatial Ecosystem and Population Dynamics Model
SPC	Secretariat of the Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
TNC	The Nature Conservancy
UNFCCC	United Nations Framework Convention on Climate Change
USP	University of the South Pacific

Workshop summary

OPENING OF THE MEETING

On behalf of the Secretariat of the Pacific Community (SPC), Dr Mike Batty, Director, Division of Fisheries, Aquaculture and Marine Ecosystems welcomed the participants. He spoke of the importance of fisheries and aquaculture, particularly tuna, to economies and communities in the Pacific and of how climate change is expected to affect fisheries in the region. He highlighted how the SPC continues to work towards sustainable fisheries in the region, and to support Pacific island countries and territories (PICTs) to understand how climate change will affect their fisheries and take action. He spoke of the ultimate aim of the Workshop to help PICTs to understand how climate change may affect the plans outlined in "The Future of Pacific Island Fisheries" study commissioned by the Forum Fisheries Agency (FFA) and the SPC on behalf of their members to maintain or improve the benefits they derive from fisheries and aquaculture. He thanked the participants again for their attendance and emphasized that he felt the Workshop would be productive in identifying and discussing suitable adaptation measures for governments, enterprises, communities and other stakeholders to reduce the risks that climate change poses and to capitalize on opportunities.

On behalf of the Food and Agriculture Organization of the United Nations (FAO), Cassandra De Young again welcomed the participants and thanked them for their attendance. She outlined FAO's perspective on the importance of fisheries and aquaculture globally and the issues facing the sector, including the strong emphasis that FAO places on linking science to policy and assisting countries to implement climate change adaptation strategies to reinforce ecological, economic and social resilience through: (i) adaptive management strategies within the ecosystem approach to fisheries and aquaculture and the Code of Conduct for Responsible Fisheries (the Code); (ii) available tools such as livelihood diversification, implementation of flexible use and management rights, finding the right mix of public and private insurance to spread risks; (iii) technological innovations, such as in vessel and port designs, availability of resistant species, information sharing mechanisms, post-harvest methods; and (iv) planning for adaptation and ensuring policy coherence across sectors including disaster preparedness. Ms De Young reminded the participants about the role the sector may play in greenhouse gas mitigation strategies by: (i) supporting the natural abilities of aquatic systems to remove and store greenhouse gas emissions; (ii) providing renewable aquatic biofuels to avoid emissions; and (iii) reducing the sector's dependence on fossil fuels through increased energy efficiency. She noted the ongoing coordinated effort in addressing climate change in the fisheries sector through the Global Partnership on Climate, Fisheries and Aquaculture (PaCFA) and highlighted the overall importance of communication and cooperation in dealing with climate change.

INTRODUCTION TO THE AGENDA AND ARRANGEMENT OF THE SESSIONS

Dr Johann Bell, Principal Fisheries Scientist (Climate Change) at the SPC, outlined the objectives of the Workshop, introduced the facilitators for each day and provided an overview of the agenda (Annex 1); in particular, how each of the presentation and breakout sessions would run and the groups for the breakout sessions. He went on to provide background to the Workshop, summarizing the 3.5 year SPC-led project that assessed the vulnerability of fisheries and aquaculture to climate change in the 22 PICTs of the region (Bell, Johnson and Hobday, 2011; Bell *et al.*, 2011). He explained the future scenarios and projections used for the assessment, and provided details on the scope of the findings.

BACKGROUND AND OBJECTIVES OF THE WORKSHOP

Fisheries and aquaculture are vital to the development goals of the Pacific Islands region (see Contributed Paper section). Nowhere else in the world do so many countries and territories depend as heavily on benefits derived from catching or growing fish and shellfish. Industrial fish-processing operations and fishing fleets account for a substantial proportion of gross domestic product (GDP) in several countries and territories. Licence fees from distant-water fishing nations make even more significant contributions to government revenue, especially for small island States.

Fish is also a cornerstone of food security in the region. Fish consumption is at least two to four times greater than the global average in more than half of all PICTs. In rural areas, most animal protein and fish consumed (60–90 percent) comes from subsistence fishing.

Fisheries and aquaculture are also an important source of jobs and opportunities to earn income. More than 12 000 people are employed in tuna canneries or processing facilities, or on tuna fishing vessels, throughout the region. Fishing also makes important contributions to livelihoods in rural areas – an average of 47 percent of households in coastal communities across the region earn either their first or second income from fishing. In some remote atolls, pearl farming is an important source of employment, and in inland Papua New Guinea there are now more than 10 000 freshwater fish farms.

To maintain or improve the important contributions made by fisheries and aquaculture in the face of the many drivers affecting the sector, many PICTs are implementing the plans required to: (i) optimize the economic benefits derived from industrial tuna fisheries; (ii) provide sufficient fish for the food security for rapidly growing populations; and (iii) identify the number of livelihoods that can be sustained from coastal fisheries and aquaculture.

Climate variability and climate change are among these drivers, and climate change is expected to increase progressively in significance. The SPC and FAO are assisting PICTs to understand how climate change may affect their plans to maintain or improve the benefits they derive from fisheries and aquaculture. The SPC has coordinated a comprehensive assessment of the vulnerability of tropical Pacific fisheries and aquaculture to climate change (Bell, Johnson and Hobday, 2011; Bell *at al*., 2011), and FAO has produced a global overview of the current scientific knowledge and adaptation and mitigation options for the sector (Cochrane *et al*., 2009).

WORKSHOP OBJECTIVES

The objectives of the Workshop were to provide the heads of fisheries and national focal points for climate change and disaster risk management (DRM) from PICTs with a sound understanding of the main projected effects of existing climate variability, global warming and carbon dioxide emissions on the ecosystems supporting fisheries and aquaculture, the consequences for current and future production, food security and livelihoods, and the actions required to minimize the risks and maximize the opportunities.

An interactive format allowed representatives from PICTs to work closely with a broad range of technical experts to:

1. Understand the direct and indirect effects of climate change, including potential natural disasters, and ocean acidification on oceanic, coastal and freshwater fish stocks and aquaculture production.
2. Identify the implications of the projected changes to fisheries and aquaculture activities on economic development, food security and livelihoods.

3. Choose and prioritize the adaptations and policies needed to build the resilience of enterprises and communities to the projected threats and to equip them to take advantage of the potential opportunities.
4. Plan the actions needed to raise the support required to implement priority adaptations and monitor their success.

UNDERSTANDING THE PROJECTED CHANGES TO SURFACE CLIMATE AND THE PACIFIC OCEAN

Through presentations by Dr Janice Lough, Dr Alex Sen Gupta and Dr Alexandre Ganachaud, participants learned about projected changes to surface climate in the tropical Pacific, including warmer temperatures, increased rainfall in tropical areas, more extreme weather events, the possibility of more-severe but less-frequent cyclones, continued El Niño-Southern Oscillation (ENSO) variability, and the probability that these changes are likely to accelerate. Delegates also learned about observed changes to the tropical Pacific Ocean. In particular, the ocean has warmed, the sea level has risen, ocean pH has declined and low oxygen areas have expanded. The continued changes projected to occur this century include: further ocean warming, greater stratification of the water column, changes to major currents, decreased nutrient supply, reduced O_2 below the mixed layer, and the decline of aragonite concentration below critical thresholds. The presenters emphasized that climatic variability would continue to occur over and above projected climate change and that this variation would be noticed as extreme events became more extreme.

The breakout groups following these presentations, helped delegates strengthen their existing knowledge of climate change issues and reinforced the key messages with robust examples. These groups discussed the important issues of how to use the model projections at the local and/or country level (downscaling) and how to mainstream climate change into national and regional initiatives (e.g. the Micronesian Challenge). Participants acknowledged that they need to be prepared for the effects of climate change on fisheries and aquaculture because they are such important industries in the region. They also encouraged the meeting to realize that these messages need to incorporate traditional knowledge and be communicated appropriately at the grass-roots level using simple messages to raise awareness of vulnerability and the steps that can be implemented to adapt.

UNDERSTANDING PROJECTED CHANGES TO TUNA

Building on the knowledge of the projected changes to the ocean, delegates heard a presentation from Dr Valerie Allain about the five provinces of the tropical Pacific Ocean, how they support different food webs for tuna, and the changes likely to occur to these provinces that are expected to alter these food webs. The projected changes to the provinces include contraction of the nutrient-rich equatorial upwelling and expansion of the Warm Pool to the east, together with greater stratification of the water column and corresponding decreases in food resources for tuna.

Dr Patrick Lehodey then explained the use of the Spatial Ecosystem and Population Dynamics Model (SEAPODYM) to project how tuna catches are expected to be affected by climate change. Participants learned how tuna are likely to be affected by ocean warming, reduced O_2 and the reduced primary production in the ocean. The distribution of skipjack tuna is projected to extend further eastward over time, with catches eventually decreasing in the west. The situation for bigeye tuna is expected to be different, with stocks eventually decreasing across the region. The meeting also heard new preliminary analyses for albacore, which is expected to contract in range and decline in biomass as oxygen levels are affected by climate change. Dr Lehodey concluded by outlining the steps needed to improve the models used to forecast the effects of climate change on tuna: better global climate models for the physical, chemical and biological process in the tropical Pacific Ocean; and reporting of tuna catches from the high seas on much finer spatial scales. It was recognized that a better understanding of biological processes would depend on more observations (long-term monitoring) of the responses of food webs for tuna to climate change.

Within the breakout groups, participants found the description of stratification useful and how it affects the nutrients needed to support tuna food webs. They also identified the need for more information on implications of declines in primary productivity for coastal fisheries. There was also great interest in the projected changes to tuna catches, particularly in the reliability of the modelling, given the potential strong implications for changes in tuna distribution and abundance for the many locally based and foreign industrial fishing operations in the region and for national economies.

UNDERSTANDING PROJECTED CHANGES TO COASTAL FISHERIES

To inform the Workshop about the projected effects of climate change on coastal fisheries, Dr Janice Lough and Johanna Johnson began by making presentations on how the habitats supporting coastal fisheries (coral reefs, mangroves, seagrasses and intertidal flats) were likely to be affected. Delegates heard how coral reefs are vulnerable to climate change primarily through rising sea surface temperatures, ocean acidification, and more intense cyclones. Impacts have already been observed resulting from increases in sea surface temperature (e.g. mass coral bleaching, decreased coral diversity and reduced reef complexity). Although the combination of the projected impacts is not expected to cause reefs to disappear, the reefs of the future will be less complex systems that provide less structural habitat for fish and shellfish.

Participants also heard how seagrass, mangroves and intertidal flats are vulnerable to sea-level rise, rising sea surface temperatures, more intense cyclones and changing rainfall patterns. As a result, these habitats are projected to decline in area, although landward migration should be possible if there are no barriers to such migration. The speakers emphasized that good management of catchments, to ensure that all coastal habitats are not subject to increased runoff of sediments, nutrients and pollution, will help build resilience to climate change.

Professor Morgan Pratchett then informed the Workshop about the direct and indirect effects of climate change on the three main groups of coastal fisheries: demersal (bottom-dwelling) fish, nearshore pelagic fish and invertebrates. Demersal fish are most vulnerable to the indirect effects of habitat degradation, although changes in water temperature and ocean currents are also expected to have direct effects on the reproduction, dispersal and growth of these fish, and ocean acidification may affect the survival of larvae settling on reefs. The effects on nearshore pelagic fish are expected to be similar to those projected for tuna, although other nearshore pelagic species are likely to be influenced by local changes in coastal productivity related to nutrient supply. Many of the invertebrates are expected to be vulnerable mainly to ocean acidification and habitat degradation.

Fisheries productivity of demersal fish and invertebrates is expected to decline, with decreases in demersal fish of about 20 percent by 2050 and 20–50 percent by 2100 under the Intergovernmental Panel on Climate Change (IPCC) A2 emissions scenario[1]. However, it will be difficult to separate the effects of climate change from the effects of other stresses on habitats and stocks over the next two to three decades. Priority adaptations include protecting coastal fish habitats to build their resilience to climate change, diversifying coastal fisheries activities and including climate change implications into fisheries management. Because demersal fish, nearshore pelagic fish and invertebrates have different vulnerabilities to climate change, heads of fisheries heard how it will be important to collect separate catch information for these three groups of coastal fisheries resources in the future to help monitor the effects of climate change.

[1] For a description of the various IPCC emissions scenarios, see www.ipcc.ch/

The breakout groups were concerned about the vulnerability of coral reefs, mangroves and seagrasses and how this will affect fish and shellfish that are an important source of food for coastal communities. Delegates identified the need to raise political awareness about the importance of these habitats to fisheries, and to promote investments and supporting policies to protect these habitats to build resilience to climate change. Mangrove replanting was discussed as one viable adaptation strategy, and participants suggested better exchange of knowledge on replanting species among countries and territories.

UNDERSTANDING PROJECTED CHANGES TO AQUACULTURE

Dr Tim Pickering informed the Workshop about the value of mariculture (coastal aquaculture) and the projected changes due to climate change. Overall, this part of the sector is vulnerable to climate change in a number of ways, e.g. ocean acidification is expected to affect the efficiency of collecting the spat of pearl oysters and the quality of the nacre that forms pearls. Ocean acidification is also likely to affect the appearance and value of cultured shrimp, whereas higher water temperatures will exacerbate stratification within ponds and increase the loss of shrimp crops through deoxygenation of the water. Higher rainfall will reduce the number of sites suitable for growing seaweed and increase the incidence of seaweed diseases. Participants learned that the location of mariculture facilities affects the vulnerability of some farming operations to higher temperatures, inundation and/or storm damage. Adaptations include moving pearl farms into deeper cooler waters, appropriate site selection (or relocation of sites) for seaweed farms and raising the wall and floor height of shrimp ponds so that they continue to drain as the sea level rises.

During a second presentation by Dr Pickering, the Workshop learned that, whereas climate change was likely to decrease the efficiency of mariculture, the productivity of freshwater aquaculture is expected to be enhanced by higher water temperatures and greater rainfall. Such changes will allow tilapia and milkfish to grow faster in ponds and for ponds to be built in more areas, including at higher elevations in the case of tilapia farming. *Macrobrachium* prawn aquaculture is also likely to benefit in the short term, but increasing temperatures are likely to have negative effects on prawn farming in the longer term. The breakout group discussions were interested in the range of potential impacts to mariculture and the implications for their future plans and opportunities for diversifying livelihoods away from coastal fisheries and into mariculture. Participants discussed the great potential benefit of enhanced freshwater aquaculture for inland communities in Papua New Guinea, Solomon Islands and Fiji, but also the opportunities it provides for low-lying countries expected to receive more rainfall. In this regard, participants thought that milkfish has real expansion potential (and is amenable to low-cost, capture-culture aquaculture methods). For higher islands, tilapia is the only viable option for efficient expansion of freshwater aquaculture, but the meeting agreed that care was needed to reconcile the production of these fish for food security with biodiversity conservation. Participants were encouraged to follow the policies related to this issue set out in the background publications for the Workshop.

UNDERSTANDING PROJECTED CHANGES TO FRESHWATER FISHERIES

The implications of climate change for freshwater habitats and fisheries were addressed by Dr Peter Gehrke. His presentation highlighted the importance of freshwater fisheries to inland communities in the Pacific, particularly Papua New Guinea, Fiji and Solomon Islands. Increased rainfall is very likely to increase freshwater habitat availability and, therefore, fishery productivity. However, Dr Gehrke warned that in catchments that have been disturbed by unregulated mining, forestry and agriculture these benefits will be restricted. He stressed that good management of catchments and freshwater fish stocks, and prevention of unwanted invasive fish species, are important strategies to harness the future potential for increased production from freshwater fisheries. Capitalizing on the potential benefits will also eventually require more efficient methods for catching freshwater fish from expanded floodplain habitats.

Although not all countries and territories have freshwater fisheries, the breakout groups recognized their value to several members, and the discussion focused on the joint benefits to both freshwater and coastal fisheries of maintaining good vegetation in catchments to protect the habitats on which these fisheries depend.

IMPLICATIONS, ADAPTATIONS AND SUGGESTED POLICIES

Armed with the best estimates of projected changes in oceanic, coastal and freshwaters fisheries and aquaculture production, the Workshop was able to consider the implications for economic development, food security and livelihoods. Mr Mike Batty noted that tuna is a very important sector in the Pacific for government revenue and GDP, with many economies having a high dependence on tuna (e.g. canneries in American Samoa, Fiji, Papua New Guinea and Solomon Islands, and the contributions of licence fees in Kiribati, Nauru and Tuvalu). The projected changes in the distribution of tuna are expected to have proportional effects on government revenues and GDP, with the smaller nations with a high dependence on tuna in the east having the potential for increased benefits. In the west, where tuna catches are eventually expected to decline, the negative effects are expected to have a low impact on national economies owing to the relatively modest contribution of tuna fishing and processing to GDP. However, there is concern that, unless steps are taken to maintain the supply of fish to canneries as tuna are redistributed east, jobs could be lost in canneries.

Mr Batty then outlined the adaptations and policies needed to reduce the risks and capitalize on the opportunities for national economies, stressing that no future benefits will be available unless tuna stocks continue to be managed responsibly to maintain their capacity for replenishment. Wherever possible, these adaptations should be "win–win", i.e. they should address important drivers facing the sector now, and build resilience to climate change in the future. The key adaptations and supporting policies were explained, and participants were encouraged to use the summary volume for the vulnerability assessment (Bell *et al.*, 2011) to study the recommended actions in detail in order to decide which ones were relevant for national priorities and contexts.

The breakout group discussions following Mr Batty's presentation focused on the vital role of the vessel day scheme in distributing the benefits from tuna to members of the Parties to the Nauru Agreement (PNA) during ENSO events and on the flexible features of the scheme that will enable it to continue to be a practical adaptation to climate change. Participants also stressed the need for immediate reduction in fishing effort on bigeye tuna and considered the benefits of operating other fishing effort schemes and other ways of continuing the supply of fish to canneries in the future. Advantages were seen in implementing energy audits of fishing vessels, both to mitigate emissions but also to assist the marketing of tuna from the region.

The Workshop then heard presentations from Dr Johann Bell on the implications for food security and livelihoods, and the appropriate adaptations and policies to maintain the vital roles of fish in the diets of Pacific island people. This message stressed that it is not only the effects of reduced coastal fisheries production that threatened the availability of fish for food security – rapid population growth is also reducing the supply of fish per person in many countries. In fact, population growth is expected to have a greater effect than climate change for several of the larger countries in the region, especially Fiji, Papua New Guinea, Solomon Islands and Vanuatu. By 2035, a substantial gap is expected to emerge between the fish needed to supply the 35 kg of fish per person per year recommended for good nutrition and the fish available from coastal fisheries associated with coral reefs for many of these countries. Filling this gap will require diversifying coastal fisheries to make larger catches of nearshore pelagic fish (mainly tuna but also small pelagic species) and developing freshwater pond aquaculture. However, the Workshop heard that the majority of the gap will need to be filled by tuna and that countries will need to allocate progressively more of their tuna resources for this purpose (Papua New Guinea is the exception because providing access to this quantity of fish will not be possible for the large inland populations).

The key adaptations and supporting policies for maintaining the important role of fish for food security were also presented and participants were once again encouraged to use the summary volume for the vulnerability assessment (Bell *et al.*, 2011) to study the recommended actions in detail in order to decide which ones were relevant for national priorities and contexts. Participants were encouraged to think of the adaptations and polices in two ways: (i) those needed to reduce the size of the emerging gap between the fish available and the fish needed for food security through good management of coastal habitats and fish stocks; and (ii) those required to increase alternative supplies of fish to fill the gap.

Discussions by participants of the key adaptations for minimizing the size of the fish supply gap to be filled to help provide food security centred on improved management of vegetation in catchments to maintain fish habitats and "primary fisheries management" based on an ecosystem approach to keep coastal fish stocks within sustainable bounds. Both adaptations depend on effective cross-sectoral management. To help fill the gap, participants agreed that redistributing low-value tuna landed by industrial fleets at major ports to urban communities at low cost would be of great assistance to food security of the urban poor. Inshore fish aggregating devices (FADs) were also seen as the main way that coastal communities can have better access to the tuna they will need for food security in the future.

CLIMATE-RELATED DISASTERS

The Workshop recognized the great similarities in adaptations to climate change required in the fisheries sector and the adaptations needed to reduce the risk of disasters resulting from cyclones and floods. Tagaloa Cooper and Florence Poulain presented regional and global perspectives and initiatives in this important area. Participants heard how FAO is working towards integrating DRM and climate change adaptation for fisheries, fish farms and their communities. FAO emphasized that disasters are a significant threat to fisheries and aquaculture, with developing countries being the most affected and the slowest to recover. Building resilience to disaster risks is more cost-effective than responding after a disaster has occurred. Within the region, the Workshop noted that the SPC and Secretariat of the Pacific Regional Environment Programme are working towards mainstreaming DRM and climate change adaptation. The Pacific Islands Framework on Climate Change provides an overarching regional framework for this initiative.

NATIONAL AND SECTORAL CLIMATE CHANGE STRATEGIES

The Workshop participants were provided with an overview of the different mechanisms and processes in place to formulate national climate change and DRM strategies. In relation to climate change, Pepetua Latasi and Brian Dawson introduced the meeting to the processes of developing national adaptation programmes of action (NAPAs)[2] that have been supported in the five Pacific island least-developed countries under support for the United Nations Framework Convention on Climate Change (UNFCCC) Least Developed Countries Fund (LDCF). These documents set out the national approach to adaptation for the country as a whole and identified specific short-term and urgent adaptation priorities. Other processes for identifying national climate change priorities

[2] To access submitted NAPAs, see http://unfccc.int/cooperation_support/least_developed_countries_portal/submitted_napas/items/4585.php

include the national communications to the UNFCCC,[3] and developing countries will soon embark on formulating national adaptation plans (NAPs). These initiatives set out national adaptation priorities and are used as a roadmap for national responses to climate change.

The processes underpinning the development of national DRM plans and the similarities and crossover with climate change adaptation processes provide a strong justification for combining the climate change adaptation and disaster risk planning processes to formulate joint national action plans (JNAPs). Several countries have already developed JNAPs (e.g. the Cook Islands, Federated States of Micronesia, Fiji and Tonga) and several more are in the pipeline (e.g. Nauru). Brian Dawson highlighted that many of the national plans lacked sufficient detail on the actual priorities and actions that could be implemented at the sector level, and the Workshop participants were encouraged to develop more specific sector adaptation and DRM plans that could feed upwards into the national strategy documents.

CLIMATE CHANGE FINANCE

The Workshop participants were given a brief overview of the international climate change finance situation and the modalities through which climate change finance could be delivered by Brian Dawson.

Information was provided on the international commitments in place to ensure a continued increase in the amount of finance available to developing countries to support adaptation and mitigation actions. By 2020, up to US$100 billion per year could be provided to support climate change response measures. The main modalities included support to project-based activities through the UNFCCC (Green Climate Fund, Adaptation Fund, LDCF and Special Climate Change Fund), multilateral processes (via the Australian Agency for International Development [AusAID], Asian Development Bank, European Union [Member Organization], Global Environment Fund, the German Society for International Cooperation, World Bank and UN Agencies), and bilateral and non-governmental organization (NGO) sources. Apart from the well-established mechanisms for supporting project-based approaches, a range of new financing mechanisms is emerging. These mechanisms include: regional climate funds, national trust funds, direct budget support and sector-wide approaches. Many of these mechanisms are at an early stage and it is likely to be some years before they will be fully operational in the region.

The Workshop participants were also informed about the complexities and constraints in accessing funds through these different modalities and were urged to be well aware of the need to have in place the appropriate documentation and due diligence procedures required to access climate change funds. Participants were also encouraged to adopt a systematic and well-structured approach to developing fishery sector plans and project proposals that could be submitted to development partners for funding. The SPC, FAO and other agencies in the region are available to support country efforts in developing these sector-based plans and funding proposals.

ASSISTANCE FROM PARTNERS

Presentations from Conservation International, the International Union for the Conservation of Nature, the Locally-managed Marine Areas Network, the Nature Conservancy, and the University of the South Pacific provided participants with a broad understanding of the array of initiatives underway by NGOs and regional organizations that can provide support for countries and communities to build the resilience of fish habitats (coral reefs, mangroves and seagrasses) and fish stocks to climate change. The long history that many of these organizations have in working with

[3] For countries' national communications, see http://unfccc.int/national_reports/items/1408.php

national governments and communities provides a strong framework for cascading the results of the SPC's vulnerability assessment and the Code, the associated ecosystem approach to fisheries and aquaculture management, and the use of spatial planning, to communities. Partnerships between communities and NGOs will be particularly important in developing the effective "on-the-ground" adaptations needed to make a difference in the lives of Pacific island people by minimizing the risks of climate change and maximizing opportunities.

RECOMMENDED PRIORITY ADAPTATIONS IDENTIFIED BY PICTS

Melanesia

Melanesian countries were most concerned about the movement of important tuna stocks eastward, away from their exclusive economic zones (EEZs) and the projected declines in coastal fisheries, which are an important source of food. The implications identified included loss of government revenue from tuna exports and licensing fees, and potential job losses for those who directly and indirectly rely on this industry, particularly in areas with existing or future plans to expand onshore processing. With a decrease in coastal fisheries production, opportunities for communities to harvest food would be more limited. Opportunities to earn income through artisanal fishing would also decline, further reducing household capacity to buy processed food or other protein substitutes.

The priority adaptations identified are summarized below. Notwithstanding the importance of tuna fisheries to job creation in Papua New Guinea and Solomon Islands, these adaptations focused on food security issues, and demonstrate that terrestrial, freshwater and coastal ecosystems are important resources for Melanesian nations. Careful adaptation to climate change will be needed to maintain the vital contributions of these resources to food security.

Economic development and government revenue:

- Examine the implications of projected shifts in tuna to the east for national plans to domesticate more industrial tuna fishing and processing operations.
- Update measures used by national governments and the Western and Central Pacific Fisheries Commission to manage the transboundary tuna resources of the region to incorporate the projected effects of climate change on tuna on the conservative catch rates required to maintain stocks in a healthy condition.
- Strengthen fisheries management supported by long-term monitoring of the effects of fishing and climate change on tuna stocks to ensure that fishing mortality and spawning biomass are kept within sustainable bounds.

Food security:

- Conserve coastal fish habitats (coral reefs, mangroves and seagrasses), for example, through the use of locally managed marine areas and environmental impact assessment (EIA) processes to protect coastal fisheries habitats from future development.
- Promote effective sustainable land and forest management practices, such as through ten-metre riparian buffers around waterways, revegetating cleared areas, and managing infrastructure development and runoff.
- Control logging in highland areas to protect catchments and minimize soil erosion and runoff into freshwater and coastal habitats.
- Install nearshore FADs to reduce pressure on reef fisheries and provide essential protein for coastal communities.
- Encourage enterprises to distribute small tuna and bycatch landed by industrial fleets as an affordable source of food for urban communities.
- Improve markets and distribution of fish to remote inland communities and to remote islands with limited supplies of fish.

- Expand freshwater aquaculture and agriculture (poultry and livestock) to help provide animal protein to those communities with poor access to tuna.
- Monitor the effects of climate change on coastal fish production, catches of tuna around FADs and freshwater aquaculture production, and communicate the key findings to communities to assist them to adjust their adaptive strategies to secure fish for food.

Sustainable livelihoods:

- Encourage communities to develop livelihoods based on alternatives to reef-associated fisheries resources (e.g. nearshore tuna, freshwater aquaculture and mariculture).

Participants from Melanesian countries reported that significant progress has been made in developing climate change strategies and policy at the national level, including JNAPs that incorporate climate change adaptation, and that they had legislation in place that could facilitate implementation of the priority adaptation options that were identified. However, cross-sectoral cooperation was identified as a potential barrier.

Micronesia

Micronesian countries were generally concerned about the projected declines in coastal habitats and fisheries, as they provide an important source of food, particularly for isolated communities. There are relatively few alternative sources of protein for these nations, and the increasing pressure on coastal fish and invertebrates, as well as impacts on livelihoods for local fishers, are key issues. Micronesian countries cover a wide longitudinal range in the Pacific and so some countries were positive about the possible opportunities to use tuna and other nearshore pelagic fish to fill the gap in fish needed for food. They were also positive about the prospects that the projected increases in skipjack and yellowfin tuna stocks in their EEZs could yield more government revenue through licensing fees, and more local jobs through tuna processing. However, Micronesian nations in the Western Pacific were concerned about the projected declines in tuna stocks in their EEZs. The implications of sea-level rise for low-lying coastal communities, particularly on atolls, were also a major concern, with subsequent economic and social issues expected.

The priority adaptations identified by participants from Micronesia reflect the importance of licensing fees for government revenue, and regardless of whether countries were projected to experience a decrease or increase in tuna resources, effective ecosystem-based fisheries management now and into the future were highlighted. The priority adaptations also reflect the high reliance on fisheries and aquaculture for food security and income, and the isolation of many communities in Micronesia.

Economic development and government revenue:

- Promote immediate conservation and management measures (ecosystem-based management) for tuna, particularly bigeye tuna.
- Review the fishing licence conditions of foreign vessels to strengthen sustainable tuna fishing practices and prevent overfishing of targeted tuna species.
- Review safety at sea under future climate change, and promote use and dissemination of traditional navigation skills and knowledge.
- Develop and implement national tuna investment plans to capture more economic benefits from increased abundances of tuna by improving national ports to provide appropriate infrastructure and services for vessels landing and transshipping catches.
- Increase the production, productivity, resilience and complementarity of fisheries systems with other sectors such as tourism, transport and communication.
- Increase competitiveness and trade of fisheries products in domestic and international markets.

Food security:

- Foster the care of coastal fish habitats, through the promotion of mangrove and seagrass planting, EIA for land reclamations and development, and management measures that prevent overfishing.
- Support community-based management initiatives for coastal fisheries.
- Diversify aquaculture to support food security at the community level.
- Increase access to tuna for urban and rural populations by improving the distribution of low-cost tuna landed by industrial vessels transshipping their catch at major ports.
- Provide support and incentives for local communities to access nearshore pelagic fish, such as through the use of nearshore FADs.

Sustainable livelihoods:

- Strengthen collaboration between government departments, such as agriculture, fisheries and trade, to enhance sustainable fisheries, food processing capacity and value-adding of fisheries products at the community level.
- Increase awareness of, and strengthen community resilience to, climate change impacts on fisheries and low-lying villages, using traditional knowledge where relevant.
- Enhance capacity to diversify mariculture, and transfer new technologies and best practices to local communities to promote profitable enterprises for community-based farming.
- Develop coral reef ecotourism ventures to provide job opportunities and income for local communities.

Participants from Micronesia reported good progress in developing high-level national climate change frameworks, JNAPs and supporting policies, but work is now needed for specific mainstreaming of climate change adaptation and DRM into fisheries and aquaculture policies and management.

Polynesia

Polynesian countries were concerned about the projected declines in coastal fisheries and mariculture owing to the high dependence on these resources for cultural, social and economic benefits. In particular, reduced coastal fisheries productivity was expected to affect food security and local livelihoods, while declines in mariculture would also affect livelihoods. However, projected increases in tuna and nearshore pelagic fisheries in the Eastern Pacific were welcomed, based on potential opportunities to capitalize on increased catches through jobs in onshore processing and industrial fishing operations, as well as opportunities to help fill any future gaps in the fish supply required for food security. In addition, the potential impact of sea-level rise on low-lying islands was a concern for some Polynesian countries, as were the potential impacts of climate change on the incidence of ciguatera fish poisoning[4].

The priority adaptations identified reflect the fact that Polynesian countries lie mostly in the Eastern Pacific, where tuna stocks are projected to increase, and that many of these PICTs are small nations that require support and cooperation to manage risks and take advantage of opportunities. There was also an emphasis on important mariculture products and how PICTs can adapt to projected changes in productivity of pearl farming and other forms of mariculture.

[4] The dinoflagellates (*Gambiodiscus* spp.) that cause ciguatera fish poisoning in coral reef fish occur on dead coral and on the leaves of macroalgae. Climate change is expected to increase both these substrates and there is concern that the abundance of the dinoflagellates could also increase (Bell, Johnson and Hobday, 2011).

Economic development and government revenue:

- Secure continued access to the tuna required for canneries and explore options for diversifying the sources of fish.
- Apply conservative fisheries management to tuna stocks to ensure sustainable catches from these valuable resources across the region.
- Strengthen national purse-seine fleets and develop small-scale fisheries for tuna to take advantage of increasing skipjack tuna stocks in the eastern Pacific.
- Provide additional fishing infrastructure for domestic and foreign vessels as tuna resources increase, and climate-proof these investments.
- Promote energy efficiency programmes for industrial fleets.
- Facilitate the inclusion of the fisheries sector in climate change adaptation planning and policy at the national level.

Food security:

- Foster the care of coastal fish habitats, through cross-sectoral and ecosystem approaches to management, management of catchment vegetation, awareness raising, seasonal closures of spawning sites and strengthening existing monitoring.
- Capitalize on projected increases in skipjack tuna catch to secure more fish for rural and urban communities by installing nearshore FADs, improving post-harvest methods, encouraging industrial fleets to land tuna and bycatch, and distributing these fish to remote districts after simple post-harvest processing.
- Build capacity of local communities to catch and grow fish by improving their technical and business skills to develop small-scale fisheries and household pond aquaculture (where suitable sites are available).

Sustainable livelihoods:

- Expand fishing and processing operations for tuna and develop commercial freshwater pond aquaculture.
- Promote the development of gender-sensitive fish processing to include women.
- Secure national access to tuna and coastal fisheries resources for urban and rural populations to safeguard jobs for small-scale fisheries and food security.
- Diversify activity of commercial fishers that are dependent on coastal fisheries through the installation of FADs.
- Diversify small-scale mariculture (e.g. rabbitfish, prawns).
- Commission research to assist pearl farming enterprises adapt to higher water temperatures and ocean acidification.
- Develop ecotourism in ways that will not be affected by degradation to coral reefs.
- Develop green snail and other potential markets for export that are projected to increase in productivity.

Polynesian participants stated that their governments have a number of strategies in place or under development to address climate change, including JNAPs and NAPAs, as well as national sustainability plans that could incorporate climate change adaptation in the future. The integration of climate change adaptation and DRM into fisheries legislation and management was identified as a gap that needed to be addressed. The strengthening of partnerships and coordination between PICTs, regional organizations and donors was also considered to be essential to facilitate the necessary adaptations to reduce climate change risks and capitalize on opportunities, particularly for smaller nations.

SUMMARY AND RECOMMENDATIONS

The Workshop discussions considered both national and regional adaptation priorities, and supporting policy and investment. At the regional scale, there were a number of key points raised that represent recommendations by participants for a way forward.

The Workshop recognized that:

- Climate change and extreme events will cause changes in Pacific environments and fisheries that will have direct and indirect effects on everyday lives, and change the way island people do things.
- The PICTs need to act now to build the resilience of their fisheries and aquaculture, and, ultimately, their communities and economies, to future climate change impacts.
- Good fisheries management now will be important to help climate-proof national fisheries and aquaculture industries against any future declines in productivity.
- Governments need to continue to work together to manage shared oceanic fisheries resources jointly and adaptively as stocks are redistributed by climate change.
- Some PICTs stand to benefit from the projected eastward movement of tuna, and short-term actions can establish the structures to capitalize on these opportunities in the future.
- Adaptations for food security will require the cooperation of governments and industrial fleets to ensure greater access to tuna for rapidly growing urban populations.
- Sectors will need to work together to address the multiple pressures on freshwater and coastal habitats that undermine the resilience of these habitats and, ultimately, fisheries.
- Melanesian nations need to capitalize on the expected improved conditions for freshwater fisheries and inland aquaculture to contribute to food security.

With this in mind, the Workshop recommended a communiqué to foster ministerial support for national and regional adaptation to reduce the risks posed by climate change and take advantage of the opportunities. To this end, a series of discussion points were prepared for the Ministerial Forum Fisheries Committee Meeting held in Nuku'alofa, Tonga on 28–29 June 2012. The session invited ministers to discuss a number of key points:

- Recognize that climate change is likely to affect regional and national plans to optimize the benefits of fisheries and aquaculture for economic development, food security and livelihoods.
- Discuss the practical adaptations proposed in the recent vulnerability assessment coordinated by the SPC (Bell, Johnson and Hobday, 2011; Bell *et al*., 2011) that can be applied at the community, national and regional level – noting that many of these would have both short-term and longer-term benefits for sustainable fisheries management and development.
- Consider the suggestion that additional work is required by Pacific island countries to evaluate and optimize adaptations.
- In view of the above, discuss the merits of giving the fisheries sector some priority in the allocation of climate change adaptation funding.
- Discuss the opportunity to inform Pacific Island Forum Leaders of these issues at their next meeting in the Cook Islands.

Ministers noted the discussion points on threats and opportunities of climate change on fisheries and welcomed the practical adaptations identified, and agreed that additional work is required to evaluate these adaptations at the national level.

CLOSING OF THE WORKSHOP

Mike Batty thanked all participants for attending and FAO, AusAID, and the Governments of New Caledonia, Japan and Sweden for their support. He stated that the future effects of climate change on Pacific fisheries and aquaculture will present both risks and opportunities, and that a range of adaptation options are available to PICTs. Action should be taken now to raise awareness and ensure systems are in place that can help maintain the important socio-economic benefits that PICTs derive from fisheries and aquaculture. He also noted that the next steps would be to ensure that discussions from the Workshop reach fisheries ministers so that there is political support to act on the recommendations. Finally, he thanked everyone for attending and declared the Workshop closed.

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Annex 2 – Agenda

5 June 2012 (Facilitator: Johann Bell)

08.30	Registration
Session 1: Welcome and introduction	
09.00	Welcome, opening remarks and prayer – Mike Batty
09.20	FAO climate change and disasters programme – Cassandra De Young and Masa Izumi
09.40	Objectives and structure of the Workshop – Johann Bell
10.00	Coffee break
Session 2: Understanding the projected changes to surface climate and Pacific Ocean	
10.30	Observed and projected changes to surface climate – Janice Lough
10.50	Breakout groups to discuss surface climate
11.30	Observed and projected changes to the ocean, Part 1 – Alex Sen Gupta
11.50	Breakout groups to discuss the ocean, Part 1
12.30	Lunch
13.30	Observed and projected changes to the ocean Part 2 – Alexandre Ganachaud
13.50	Breakout groups to discuss the ocean, Part 2
Session 3: Understanding projected changes to tuna	
14.30	Projected changes to food webs for tuna – Valerie Allain
14.50	Breakout groups to discuss effects on food webs for tuna
15.30	Coffee break
16.00	Projected changes to tuna stocks – Patrick Lehodey
16.20	Breakout groups to discuss effects on tuna stocks
17.00	Summary Day 1 (Johanna Johnson)

6 June 2012 (Facilitator: Mike Batty)

08.00	Recap of Day 1 (Johanna Johnson)
Session 4: Understanding changes to coastal fisheries	
08.20	Projected changes to coral reefs – Janice Lough
08.40	Breakout groups to discuss effects on coral reefs
09.20	Projected changes to mangroves, seagrasses and tidal flats – Johanna Johnson
09.40	Breakout groups to discuss effects on these coastal habitats
10.20	Coffee break
10.50	Projected changes to coastal fisheries production – Morgan Pratchett
11.10	Breakout groups to discuss effects on coastal fisheries production
Session 5: Understanding changes to aquaculture	
11.50	Projected changes to coastal aquaculture – Tim Pickering
12.10	Breakout groups to discuss effects on coastal aquaculture
12.50	Lunch
14.00	Projected changes to freshwater aquaculture – Tim Pickering
14.20	Breakout groups to discuss effects on freshwater aquaculture
Session 6: Understanding changes to freshwater fisheries	
15.00	Projected changes to freshwater fish habitats and stocks – Peter Gehrke
15.30	Coffee break
16.00	Breakout groups to discuss effects on freshwater habitats and stocks
16.40	Summary of Day 2 (Johanna Johnson)

7 June 2012 (Facilitator: Cassandra De Young)

08.00	Recap of Day 2 (Johanna Johnson)
Session 7:	**Implications, adaptations and suggested policies**
08.20	Implications for economic development – Mike Batty
08.40	Breakout groups to discuss implications for economic development
09.20	Adaptations and policies for economic development – Mike Batty
09.40	Breakout groups to discuss adaptations for economic development
10.20	Coffee break
10.50	Implications for food security and livelihoods – Johann Bell
11.10	Break out groups to discuss implications for food security and livelihoods
11.50	Adaptations and policies for food security and livelihoods – Johann Bell
12.10	Breakout groups to discuss adaptations for food security and livelihoods
12.50	Lunch
Session 8:	**Climate-related disasters**
14.00	Global frameworks – Florence Poulain
14.20	The Pacific approach – Tagaloa Cooper
14.40	Breakout groups to discuss DRM and fisheries
15.10	Coffee break
Session 9:	**National priority adaptations and policies**
15.40	National climate change strategies and action plans – Pepetua Latasi
16.00	Driving priority adaptations and policies at the sector level – Brian Dawson
16.20	Working groups to identify national and regional priority adaptations, including how these fit into/are supported by existing national climate change strategies/plans
17.30	Summary of Day 3 (Johanna Johnson)

8 June 2012 (Facilitator: Andrea Volentras)

Session 9:	**National priority adaptations and policies**
08.00	Brief reports to plenary by Melanesian countries and territories
09.15	Brief reports to plenary by Micronesian countries and territories
10.30	Coffee break
11.00	Brief reports to plenary by Polynesian countries and territories
12.45	Lunch
Session 10:	**Dialogue with partners**
14.00	Overview of opportunities to fund climate change adaptation – Brian Dawson
14.20	Presentations by development agencies (ADB, AusAID, European Union [Member Organization], GIZ)
15.20	Coffee break
15.50	Statements from regional organizations/NGOs on additional assistance for PICTs (CI, IUCN, LLMA, TNC, UNDP, USP, WorldFish)
17.15	Summary of Workshop (clearing of summary document) (Mike Batty)
18.00	Barbecue

CONTRIBUTED PAPER

Vulnerability of fisheries and aquaculture to climate change in Pacific Island countries and territories

by

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1. Introduction

The vital contributions of fisheries and aquaculture to the collective goals of the 22 Pacific Island countries and territories (PICTs)[1] for economic, human and social development cannot be overemphasized. Nowhere else in the world do so many countries and territories depend as heavily on the benefits derived from fish and shellfish. License fees from distant water fishing nations (DWFNs) operating in the region contribute substantially to the government revenue of many PICTs and domestic fishing fleets and local fish processing operations provide account for significant proportions of gross domestic product (GDP) in several PICTs (Gillett, 2009).

Fish underpins food security in the region – in more than half of all PICTs fish consumption is at least 2–4 times greater than the global average. In the rural areas, 60–90 percent of this fish comes from subsistence fishing activities and fish often makes up 50-90 percent of dietary animal protein (Bell *et al.*, 2009). However, in some PICTs, access to fish needs to be increased to provide the 35 kg per person per year recommended for good nutrition in a region with limited opportunities for animal husbandry and broad-acre crop production (SPC, 2008a)[2].

Fisheries and aquaculture are also an important source of jobs and opportunities to earn income. More than 12 000 people are employed in tuna canneries or processing facilities, or on tuna fishing vessels, and an average of 47 percent of households in coastal fishing communities earn either their first or second income from fishing or selling fish (Pinca *et al.*, 2010). In several remote atolls, pearl farming is an important source of employment and in inland Papua New Guinea there are now more than 10 000 households growing fish in freshwater ponds (Ponia, 2010, Pickering *et al.*, 2011).

The Pacific Plan[3] recognizes that the benefits of the fisheries and aquaculture sector for economic development, food security and livelihoods are linked to the effective management of fish and shellfish, and the habitats that support them. '*Development and implementation of national and regional conservation and management measures for the sustainable use of fisheries resources*' is a priority of the Plan. The need for responsible and effective stewardship of fisheries resources was also reinforced by Pacific Islands Forum Leaders in their 'Vava'u Declaration'[4].

'The Future of Pacific Island Fisheries' study commissioned by the Pacific Islands Forum Fisheries Agency (FFA) and the Secretariat of the Pacific community (SPC) (Gillett and Cartwright, 2010) maps out the management measures needed to retain the benefits of the sector. It also identifies the main factors driving exploitation of the various stocks underpinning the sector and plausible scenarios that could result in the benefits derived from these resources being reduced or lost. One driver that is very likely to grow in significance in coming years is the effects of global warming and ocean acidification due to increased emission of carbon dioxide (CO_2) and other greenhouse

[1] The 22 Pacific Island countries and territories are American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Commonwealth of the Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn Islands, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and Wallis and Futuna.

[2] Papua New Guinea is the exception because it is not possible to plan for such levels of fish consumption for the large and remote inland populations.

[3] www.forumsec.org/resources/uploads/attachments/documents/Pacific_Plan_Nov_2007_version.pdf

[4] www.forumsec.org/resources/uploads/attachments/documents/THE%20Vava'u%20declaration.pdf

gases. There are serious concerns that these emissions could soon begin to affect the plans being made by PICTs to optimize the economic and social benefits derived from fisheries and aquaculture.

1.1 Objectives of the study

This case study assesses the vulnerability of the fisheries and aquaculture sector in PICTs to climate change by examining: 1) the potential impacts of projected changes to the atmosphere and ocean on oceanic, coastal and freshwater fish habitats and stocks, and aquaculture; 2) the sensitivity and adaptive capacity of these resources and the economies and communities that depend on them to such changes; 3) the adaptation strategies and policies required to minimize the threats from climate change and maximize opportunities; 4) the gaps in knowledge remaining to be filled to improve understanding of the sector's vulnerability; and 5) the recommended investments needed to launch priority adaptations and regularly assess their success.

This analysis is based on the recent assessment of the vulnerability of fisheries and aquaculture in the tropical Pacific to climate change coordinated by SPC (Bell *et al*., 2011a).

Although some of the fisheries resources of the region, e.g. tuna, are shared with countries in Southeast Asia (particularly Indonesia and Philippines), this case study is restricted to assessing the vulnerability of island nations in the tropical Pacific. The outcomes of the assessment are expected to have some application to small island developing states (SIDS) in the Indian Ocean and Caribbean, however, the wide geographic separation of PICTs from the other SIDS warrants an independent case study.

2. Economic-social fisheries and aquaculture systems of the tropical Pacific

The 22 PICTs span much of the tropical and subtropical Pacific Ocean from 25°N to 25°S, and 130°E to 130°W, an area exceeding 27 million km^2 (Figure 1)[5]. The ocean area bounded by PICTs represents most of the tropical portion of the Western and Central Pacific Ocean (WCPO) defined in the Western and Central Pacific Fisheries Convention.

This vast region is one of great geological, biological and social diversity, which has historically been divided into three subregions (Melanesia, Micronesia and Polynesia) (Figure 1) based on the physical nature of the islands, biogeography, and ethnic/cultural factors.

2.1 Physical nature of the islands

In the west of the region, high islands dominate the landscape of Melanesia, which includes Fiji Islands (Fiji), New Caledonia, Papua New Guinea (PNG), Solomon Islands and Vanuatu (Figure 1). The large sizes of these high islands have supported the expansion of human settlement by providing opportunities for agriculture, fisheries, forestry and mining. In addition, the coastal waters surrounding the islands of Melanesia are relatively productive due to 1) nutrients delivered from terrestrial runoff; and 2) the occurrence of small-scale, nutrient-rich upwellings created by deflection of large-scale ocean currents around the islands (Ganachaud *et al*., 2011).

Local climate is also affected by the size of the islands in Melanesia, which intercept the monsoons and trade winds and generally receive much higher rainfall than the low-lying islands further to the east. However, the windward (usually eastern) sides of high islands typically receive more rain than the leeward (usually western) slopes.

The relatively large size of Papua New Guinea makes it distinct from the other PICTs – its land area and population are greater than those of all the other PICTs combined (Annexes 1 and 2). The geography of Papua New Guinea has a significant influence on the surrounding ocean and on the nation's fisheries and aquaculture activities (Gillett, 2009; Ponia, 2010).

Further eastwards and northwards of Melanesia are the countries and territories of Micronesia and Polynesia (Figure 1). The islands within these subregions are usually smaller than those in Melanesia (Annex 1) and can be considered to be 'atolls' in various stages of evolution. They range from geologically recent volcanic peaks surrounded by a narrow fringing reef, to partially subsided peaks surrounded by a lagoon, to fully evolved atolls, i.e. ring reefs formed around a completely submerged peak (Bell *et al*., 2011b). Consequently, the islands of Micronesia and Polynesia vary greatly in the size and extent of their lagoons and their capacity to support a diverse range of habitats and resources for fisheries and aquaculture.

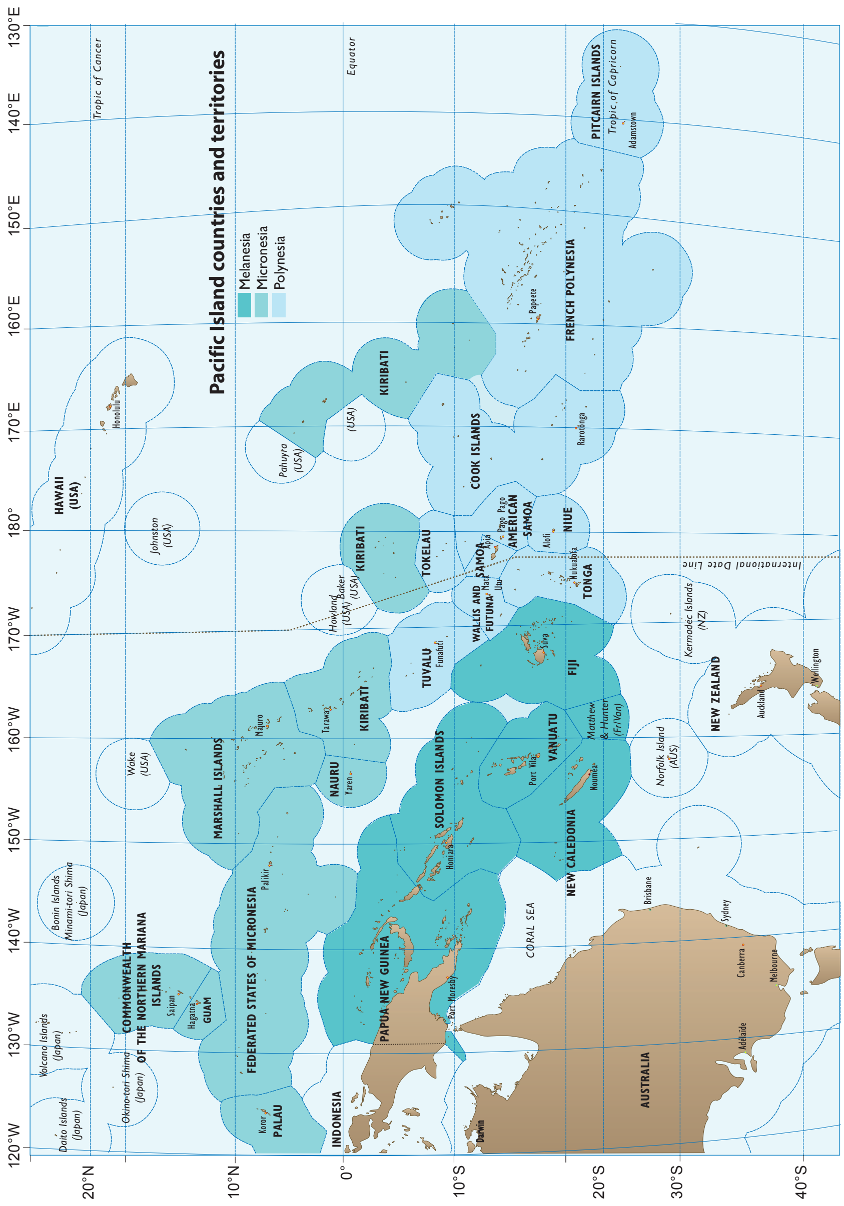
2.2 Biogeography

There is a general reduction in marine biodiversity from west to east across the region, proportional to the distance from the centre of Indo-Pacific diversity in insular

[5] This map is indicative only of agreed and potential maritime boundaries between Pacific Island countries and territories (PICTs). It does not reflect the claims of PICTs to offshore areas.

FIGURE 1

The exclusive economic zones of Pacific Island countries and territories. The subregions of Melanesia, Micronesia and Polynesia are also shown



Source: Bell *et al.* 2011b.

Southeast Asia (MacArthur and Wilson, 1967; Briggs, 2005). For example, the number of fish species associated with coral reefs decreases from about 1 600 in PNG to 600 in French Polynesia (FishBase, 2012). The number of coral reef fish species used for subsistence and livelihoods also decreases from west to east (Pinca *et al.*, 2010). Similarly, there is a lower diversity of hard and soft corals (Karlson *et al.*, 2004), seagrasses (Green and Short, 2003) and mangroves (Ellison, 2006) in the eastern than in the western tropical Pacific.

The great biodiversity of the western tropical Pacific is recognized internationally and has resulted in high-level marine conservation initiatives in many of the countries in this area. These include the Coral Triangle Initiative, involving Indonesia, Malaysia, Philippines, Timor Leste, PNG and Solomon Islands, and the Micronesia Challenge underway in the Federated States of Micronesia (FSM), Guam, Marshall Islands, Commonwealth of the Northern Mariana Islands (CNMI) and Palau.

2.3 Ethnic and cultural diversity

The broad ethnic and cultural distinctions among the people of PICTs coincide generally with the geomorphological differences between the islands. Melanesians inhabit the larger high islands in the southwest of the region, while Micronesians occupy the smaller islands to the north and Polynesians the islands to the east (Figure 1). However, there has been integration of these ethnic groups in some PICTs, particularly in Fiji but also in Solomon Islands and Papua New Guinea, where Polynesian communities have been established on the outlying islands. People from Micronesia (Kiribati) have also been resettled in Solomon Islands, and New Caledonia has a significant Polynesian population from Wallis and Futuna and French Polynesia.

A consequence of the large differences in availability of land across the region (Annex 1) is that Micronesians and Polynesians generally have a strong affinity with the sea and fishing, whereas most Melanesians have a stronger culture of using agricultural methods to produce food. This is reflected in the generally lower fish consumption per person in PNG, Vanuatu and New Caledonia (Bell *et al*., 2009).

2.4 Demography

The populations of many PICTs are increasing. In 2010, the total population of all PICTs combined was estimated to be 9.9 million people, and is projected to rise by about 50 percent to about 15 million in 2035 (Annex 2). Most of the region's population is concentrated in Melanesia, which also has higher population growth rates in general[6]. PNG alone accounted for 69 percent of the regional population in 2010 and is predicted to contribute 79 percent of the regional population growth by 2035 (Annex 2). However, some of the smallest PICTs (Cook Islands, Nauru, Niue, Tokelau, Tuvalu) have experienced a population decline in recent years due to emigration. Another trend is rapid urbanization, caused by migration from outer islands and rural areas within larger countries to the main population centres. In PNG, urban populations are predicted to increase by 180 percent by 2035, compared to a total population increase of 60 percent.

2.5 Nature of local economies and limitations to economic development

The economies of PICTs are diverse, but all are characterized by the constraints typical of small island islands, particularly the effects of geographic isolation (Adams, 1998). Tourism plays the major role in some economies, including those of Cook Islands, Fiji, French Polynesia, Guam, CNMI and Palau. Other countries and territories in Melanesia and Nauru have derived economic benefits from forestry, agriculture and/or mineral resources. Several of the smaller island nations are heavily dependent on remittances from family members working overseas. But in almost all PICTs, fisheries play a much larger role in the economy than in most other countries (Gillett and Lightfoot, 2001; Gillett, 2009).

Oceanic (mainly tuna) fisheries are one natural asset that PICTs have which are not limited by the small sizes of their islands. Geographic isolation has helped protect these valuable fisheries from the overexploitation afflicting many stocks elsewhere in the world (FAO, 2010a). The potential to develop the tropical Pacific tuna fishery within the limits set by regional and international agreements is of great interest to several PICTs. In particular, the transfer of capacity from DWFNs to PICTs promises to deliver substantial economic returns (FFA, 2010). There are, however, constraints to the onshore development of the processing facilities needed to domesticate the benefits of tuna fisheries in smaller PICTs. These constraints include limited freshwater supplies, high freight charges, relatively high wage rates and the limited capacity of the environment and society to absorb such large-scale operations.

The other major living natural resources of the region are the forests of Melanesia. However, these resources do not have the same sustainable development potential because they have long renewal times relative to current exploitation rates. Terrestrial

[6] SPC Statistics for Development Programme (and its Pacific Regional Information System – PRISM; www.spc.int/prism.

mineral deposits promise to generate wealth in the region but in Nauru primary phosphate reserves have already been exhausted. The potential for mining the sea bed is only now beginning to be assessed in detail. Tourism has significant economic potential. However, this potential will depend largely on the way tourists perceive the health of the marine environment.

2.6 Exclusive economic zones

The United Nations Convention on the Law of the Sea (UNCLOS) increased the potential for economic development and government revenue for all PICTs by allowing them to declare national exclusive economic zones (EEZs) (Figure 1). UNCLOS provided international recognition of the vast areas over which Pacific Island states could exercise sovereign rights (Annex 1).

The sovereign rights over EEZs also carry the responsibility for conservation and management of resources. PICTs have a long history of regional cooperation in this regard, particularly in managing the region's highly migratory tuna stocks. The FFA was established to allow members to cooperate in the management of tuna resources within their EEZs. The subsequent establishment of the Western and Central Pacific Fisheries Commission (WCPFC) enables PICTs to 1) cooperate with other states for the conservation and management of tuna resources and associated species in the high seas; and 2) impose overall limits on tuna fishing across the entire distribution of the stocks, not just in their EEZs.

Regional cooperation in fisheries science is supported by SPC's Fisheries, Aquaculture and Marine Environment Division, which provides PICTs with the scientific expertise and research required to understand the size and status of oceanic fisheries in the western and central Pacific.

2.7 Economic and social contributions of fisheries and aquaculture

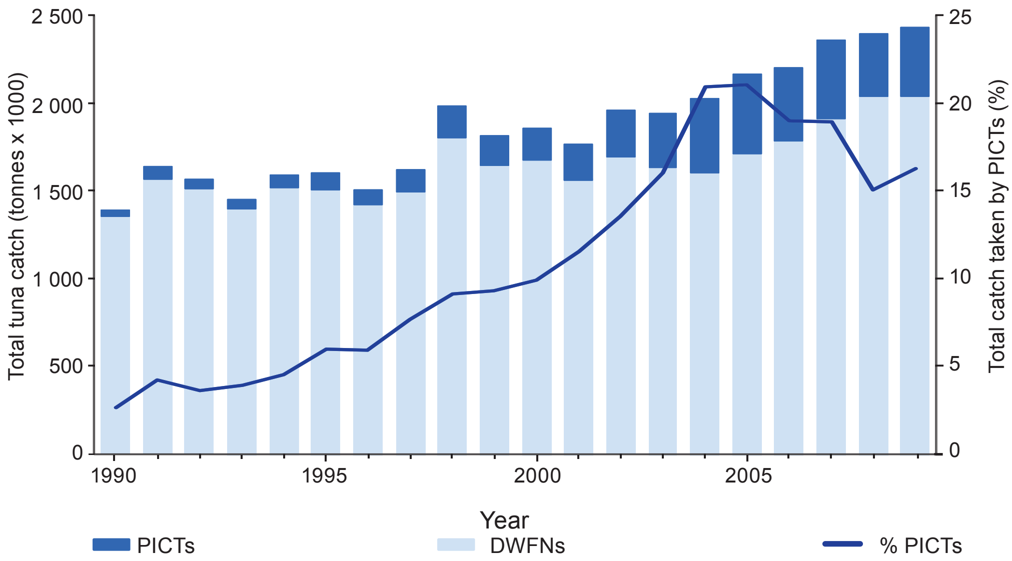
Across the Pacific Islands region it is widely recognized that fisheries and aquaculture make vital contributions to economic development, government revenue, food security and livelihoods (Gillett, 2009; Gillett and Cartwright, 2010; Bell *et al*., 2009; 2011a). In general, industrial tuna fisheries contribute to economic development, government revenue and fulltime jobs, whereas coastal and freshwater fisheries and aquaculture help provide food security and a source of income for rural communities. The magnitude of these contributions makes PICTs with small economies highly vulnerable to any changes in productivity of fisheries and aquaculture, largely because they have limited options to generate wealth and jobs, or produce animal protein, from other resources. The main economic and social contributions from fisheries and aquaculture in the region are summarized below.

Contributions of industrial tuna fishing to economic development and government revenue

The tuna industry in the WCPO is based on two separate industrial fisheries: 1) a surface fishery targeting schools of skipjack and juvenile yellowfin tuna using purse-seine and pole-and-line fishing methods to supply canneries in the Pacific, Asia and Europe; and 2) a longline fishery, which targets mature bigeye and yellowfin tuna for the Japanese sashimi trade and other high-value markets, and albacore for canning in American Samoa and Fiji (Gillett, 2011; Bell *et al*., 2011c). Much of the fishing occurs within the EEZs of PICTs, but also on the high seas (Figure 1). The catches made by the surface fishery in the WCPO are around ten times greater than those made by the longline fishery (Williams and Terawasi, 2010). The catch from the WCPO provided 58 percent of the estimated global tuna catch in 2009 and the catch from the EEZs of PICTs made up 48 percent of the catch from the WCPO (Williams and Terawasi, 2010).

FIGURE 2

Catches of the four main species of tuna combined from the Western and Central Pacific Ocean between 1990 and 2009 taken by fleets operating from Pacific Island countries and territories (dark) and distant water fishing nations (DWFNs) (light). The percentage of catch taken by PICTs each year is also shown



Source: Bell *et al.* 2011c.

The total tuna catch in the WCPO has doubled over the past 20 years, from 1.2 million tonnes in 1988 to about 2.5 million tonnes in 2009, mainly due to an increase in the skipjack tuna catch (Williams and Terawasi, 2010). The region's industrial tuna fishery was dominated by fleets from DWFNs for many years but the percentage of the total catch taken by domestic and locally-based vessels has increased in the last decade (Figure 2).

Surface fishery

Between 1999 and 2008, the great majority of the surface fishery catch was taken in the EEZs of the Parties to the Nauru Agreement (PNA)[7]. The average volumes and values of fish landed over this 10-year period (Table 1) are a reasonably good indication of the relative importance of the catches in each EEZ because they even out some of the El Niño and La Niña conditions that influence the distribution of skipjack tuna and fishing effort across the region (Lehodey *et al*., 1997; 2011).

Although large catches are made by the surface fishery in the EEZs of several PICTs, GDP is affected by whether the catches are landed in the country and, if they are landed, by the size of the national economy. In PNG, where the national economy is large, the significant surface fishery in the EEZ averaged only 1.5 percent of GDP from 1999 to 2008, although it was 2.8 percent at the end of this period (Table 2). For the economies of Solomon Islands and FSM, the surface fishery made up 2.3 percent and 3.3 percent of GDP over the 10-year period, respectively (Table 2).

Contributions of the surface fishery to GDP have been greatest in the Marshall Islands, where they averaged >10 percent over the 10-year period and were 21 percent in 2007 (Table 2).

Processing catches from the surface fishery can be a significant part of GDP in some PICTs (Bell *et al*., 2011c). American Samoa provides the best example, where the

[7] PNA members are: Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands and Tuvalu www.pnatuna.com

TABLE 1

The average annual catch and value of the surface tuna fishery for national fleets and foreign fleets in the exclusive economic zones (EEZs) of selected Pacific Island countries and territories (PICTs) between 1999 and 2008. Average total volume and value of the catch made by national fleets across the Western and Central Pacific Ocean as a whole is also shown, together with average annual landings by national and foreign fleets at ports within PICTs

PICT	Average annual catch (tonnes)			Average annual catch value (USD million)			Average port landings (tonnes)**	
	National fleet		Foreign fleet	National fleet		Foreign fleet	National fleet	Foreign fleet
	EEZ	Region	EEZ	EEZ	Region	EEZ		
Melanesia								
Fiji	465	465	248	1.44	1.44	0.77	0	3 939
PNG*	97 933	158 594	221 792	105	170.4	203	55 762	88 627
Solomon Islands*	20 829	22 369	49 449	19.7	21.1	46.7	8766	57 578
Vanuatu	0	43 523	77	0	43.5	0.06	0	193
Micronesia								
FSM*	3 227	19 247	152 349	2.67	15.9	126	9 796	196 053
Guam	0	0	17	0	0	0	0	0
Kiribati*	335	5 332	180 851	0.28	4.52	153	132	61 068
Marshall Islands*	2 756	35 777	22 530	2.44	31.7	20.0	32 511	121 524
Nauru*	0	0	63 063	0	0	52.4	0	2 115
Palau*	0	0	1 815	0	0	1.83	0	203
Polynesia								
American Samoa	0	0	49	0	0	0.04	0	107 620
Cook Islands	0	0	650	0	0	0.44	0	0
French Polynesia	623	636	80	0.52	0.53	0.07	172	87
Samoa	0	0	60	0	0	0.03	0	363
Tokelau	0	0	2 664	0	0	2.00	0	0
Tuvalu*	0	0	26 379	0	0	22.6	0	0

Source: Bell *et al.* 2011d.

* Parties to the Nauru Agreement; ** representative values only, derived from logsheet, port sampling and landings data.

recent value of manufacturing outputs was 22.3 percent of GDP, worth around USD 100 million. When the value of post-harvesting of tuna is added to the fishing operations in Solomon Islands the combined contribution to GDP increases to 4.6 percent.

Contributions of foreign access fees by DWFNs engaged in the surface fishery to government revenue are of greater importance to many PICTs than the contributions of this fishery to GDP (Gillett, 2009). Contributions to government revenue average between 3 percent and 42 percent of the total tax base for seven PICTs (Table 2) and are particularly important to the smaller economies within the PNA (Kiribati, Nauru and Tuvalu), and to FSM. Some governments also gain revenues from a variety of sources associated with the surface fishery, including transshipment revenues and licence fees paid by operators of domestic tuna vessels.

Longline fishery

Longline vessels operate more widely across the WCPO than the purse-seiners in the surface fishery, and much of the catch from this lower volume/higher value fishery is taken outside the EEZs of PICTs (Williams and Terawasi, 2010). Nevertheless, national longline fleets from 15 PICTs operate within their own EEZs, and relatively large catches (1 400–6 600 tonnes per year) are made by Cook Islands, Fiji, French Polynesia, New Caledonia, PNG and Samoa. Longline fleets from several PICTs also fish elsewhere in the region (Bell *et al.*, 2011c). PICTs often land the majority of their longline catch at their own ports, although the Samoan vessels land much of their fish in American Samoa.

Longline vessels from DWFNs have also operated in the EEZs of most PICTs. The greatest longline catches by DWFNs are made in Kiribati, where the total

TABLE 2
Contributions of the surface tuna fishery to gross domestic product (GDP), and total government revenue (GR) through payment of access fees by distant water fishing nations, to Pacific Island countries and territories (PICTs) in USD, and in percentage terms. Contributions to GDP relate only to fishing operations and do not include post-harvest activities

PICT	GDP	Contribution to GDP				Total government revenue	Foreign access fee revenue 2007	
		Locally based purse-seine and pole-and-line fleets						
		Estimate based on 1999–2008 average		2007*				
	USD million	USD million	% GDP	USD million	% GDP	USD million	USD million	% GR
Melanesia								
Fiji	3 290	0.7	0.02	0	0	920	0.26[b]	< 0.1
New Caledonia	8 829	0	0	0	0	996	0	0
PNG	5 708	85.2	1.49	161	2.82	2 599	14.97[b]	0.6
Solomon Islands	457	10.5	2.31	14	3.07	267	11.76[b]	4.4
Vanuatu	500	0	0	0	0	79	1.36	1.7
Micronesia								
FSM	237	7.9	3.35	7.8	3.28	145	14.76	10.2
Guam	3 679	0	0	0	0	428	0	0
Kiribati	71	0	0	0	0	51	21.36	41.9
Marshall Islands	156	15.8	10.16	32.7	20.95	93	1.95	2.1
Nauru	22	0	0	0	0	30	6.13[b]	20.4
CNMI	633	0	0	0	0	193	0	0
Palau	157	0	0	0	0	36	1.12	3.2
Polynesia								
American Samoa	462	0	0	0	0	155	0	0
Cook Islands	211	0	0	0	0	86	0.26[b]	0.3
French Polynesia	5 478	0.3	< 0.01	nea	nea	865	0	0
Niue	10	0	0	0	0	12	0.26[b]	2.2
Pitcairn Islands	nea	0	0	0	0	7	0	0
Samoa	524	0	0	0	0	168	0.26[b]	0.1
Tokelau	nea	0	0	0	0	13	1.48[b]	11.4
Tonga	238	0	0	0	0	76	0.13[b]	0.2
Tuvalu	15	0	0	0	0	31	3.45	11.1
Wallis and Futuna	188	0	0	0	0	nea	0	0

Source: Bell *et al.* 2011d.

* Derived from Gillett (2009); a = estimates are for aggregate access fee revenues for foreign pole-and-line, purse-seine and longline fleets as provided by Gillett (2009); b = PICTs which did not receive access fee revenues from foreign longline fleets between 2006 and 2008 or which usually receive > 90% of their total access fee revenue from foreign fleets operating in the surface fishery; nea = no estimate available.

catch averaged 8 800 tonnes per year between 1999 and 2008. Catches by DWFNs relative to the national fleet are also high in FSM, Marshall Islands, Palau, Solomon Islands and Vanuatu but are lower than those taken by the national fleet for nine PICTs (Bell *et al*., 2011c). Fleets from DWFNs mainly offload their catch in Fiji and American Samoa, although Palau, Marshall Islands, FSM and French Polynesia are also used to land large catches.

The lower volumes and values of fish caught by the longline fishery compared to the surface fishery result in more limited contributions to GDP and government revenue from longlining in most PICTs (Gillett, 2009; Bell *et al*., 2011d).

Jobs derived from tuna

More than 12 000 formal full-time and part-time jobs have been created through tuna fishing and processing in PNG, American Samoa, Fiji and Solomon Islands (Table 3). There is strong interest within the region in creating even greater employment opportunities and wider economic benefits from tuna resources by attracting foreign

TABLE 3
Number of jobs in Pacific Island countries and territories (PICTs) on tuna vessels and in shore-based operations (e.g. canneries). Also shown is the average percentage of households in 4–5 coastal communities in each of 17 PICTs that earned their first or second income from fishing, and the number of jobs in aquaculture

PICT	Local jobs on tuna vessels			Local jobs in shore-based processing of tuna			Coastal household earnings from fishing (%)			Jobs in aqua-culture
	2002	2006	2008	2002	2006	2008	First income	Second income	Both incomes	
Melanesia										
Fiji	893	330	150	1 496	2 200	1 250	69.8	23.5	93.3	550
New Caledonia	Undetermined number of jobs						23.4	22.8	46.2	560
PNG	460	110	440	2 707	4 000	8 550	53.3	32.5	85.8	> 10 000
Solomon Islands	464	66	107	422	330	827	29.1	31.8	61.0	610
Vanuatu	54	20	30	30	30	30	21.4	39.8	61.1	30
Micronesia										
FSM	89	36	25	131	24	140	47.9	4.6	52.5	20
Guam	Undetermined number of jobs						nea	nea	nea	20
Kiribati	39	15	15	47	80	70	33.3	24.8	58.1	10
Marshall Islands	5	0	25	457	100	116	36.0	17.6	53.6	5
Nauru	5	0	0	10	2	0	4.9	17.1	22.0	nea
CNMI	Undetermined number of jobs						nea	nea	nea	12
Palau	1	0	0	11	5	20	10.2	15.7	25.9	5
Polynesia										
American Samoa	nea	nea	nea	nea	4 757	nea	nea	nea	nea	15
Cook Islands	50	15	12	15	15	10	12.3	7.8	20.1	450
French Polynesia	Undetermined number of jobs						15.4	11.3	26.7	5 000
Niue	5	0	0	0	14	18	1.4	8.7	10.1	0
Pitcairn Islands	No jobs based on tuna						nea	nea	nea	0
Samoa	674	110	255	108	90	40	24.2	26.6	50.8	16
Tokelau	No jobs based on tuna						nea	nea	nea	0
Tonga	161	75	45	85	35	35	41.5	4.7	46.2	20
Tuvalu	59	20	65	36	10	10	24.0	24.4	48.4	0
Wallis and Futuna	No jobs based on tuna						21.1	23.2	44.3	0
Total (average)	**2 959**	**797**	**1 169**	**5 555**	**11 692**	**11 116**	**(27.6)**	**(19.8)**	**(47.4)**	**17 323**

Source: Bell *et al.* 2011d.

nea = no estimate available.

investment into locally-based fishing and processing operations. It has been estimated that each additional 100 000 tonnes of tuna retained from the surface fishery for processing in the region can create about 7 000 new jobs (FFA, 2010). Based on the number of associated jobs in government and the private sector in American Samoa, twice as many people could be employed indirectly as a result of tuna fishing and processing. More than USD 60 million has been invested in new tuna processing plants in the region in recent years and several new facilities are proposed in PNG and Solomon Islands. It must be recognized, however, that large-scale onshore processing is only viable in those few PICTs with adequate land and fresh water, and low labour costs.

Contributions of coastal and freshwater fisheries to food security

The wide variety of species caught by coastal fisheries can be separated into demersal (bottom-dwelling) fish (>50 percent of the catch), nearshore pelagic fish (about 30 percent) and invertebrates gleaned from subtidal and intertidal habitats or targeted for export (<20 percent) (Pratchett *et al.*, 2011). Most PICTs have an extraordinary dependence on these three categories of coastal fisheries for food security due to limited access to other sources of animal protein (SPC, 2008a; Bell *et al.*, 2009; Gillett, 2009). This need is reflected in the fact that the subsistence catch comprises >70 percent

TABLE 4
Estimates of annual fish consumption per person, percentage of animal protein in the diet derived from fish, and percentage of fish consumed caught by subsistence fishing, in Pacific Island countries and territories (PICTs). The amount of fish needed for food security in 2035 is also shown; blank spaces indicate that no estimate was available

PICT	Fish consumption per person (kg)				Animal protein in diet (%)		Subsistence catch (%)		Fish needed for food by 2035 (tonnes)
	National	Rural	Urban	Coastal*	Rural	Urban	Rural	Urban	
Melanesia									
Fiji	21	25	15	113			52	7	34 200[a]
New Caledonia	26	55	11	43			91	42	11 700[a]
PNG	13	10	28	53			64		140 700[b]
Solomon Islands	33	31	45	118	94	83	73	13	33 900[a]
Vanuatu	20	21	19	30	60	43	60	17	14 800[a]
Micronesia									
Guam	27								8 800[a]
FSM	69	77	67	96	80	83	77	73	7 300[c]
Kiribati	62	58	67	115	89	80	79	46	9 000[c]
Marshall Islands	39								2 200[a]
Nauru	56			62	71	71	66	66	790[c]
CNMI									4 700[a]
Palau	33	43	28	79	59	47	60	35	800[a]
Polynesia									
American Samoa		63							3 100[a]
Cook Islands	35	61	25	79	51	27	76	27	600[a]
French Polynesia	70	90	52	61	71	57	78	60	23 200[c]
Niue	79			50			56	56	100[c]
Pitcairn Islands	148								10[c]
Samoa	87	98	46	94			47	21	17 600[c]
Tokelau	~ 200								250[c]
Tonga	20			85			37	37	4 000[a]
Tuvalu	110	147	69	146	77	41	86	56	1 400[c]
Wallis and Futuna	74			56			86	86	1 000[c]

Source: Bell *et al.* 2009, 2011d; Gillett 2009).

* Applies to households in coastal fishing communities at > 4 sites; a = based on recommended fish consumption of 35 kg per person per year; b = based on the recent national average of 13 kg per person per year, rather than 35 kg, to reflect the difficulties of distributing fish to the large inland population; c = based on recent traditional levels of fish consumption (Bell *et al.* 2009).

of the total coastal fish catch of about 155 000 tonnes (Gillett, 2009), and that 50–90 percent of the fish eaten in rural areas of 14 PICTs is caught by the household from coral reefs and other coastal habitats (Table 4).

In rural communities fish consumption exceeds 50 kg per person per year in many PICTs, and is 60–145 kg in coastal communities in 11 PICTs (Table 4). Across the region, fish provides 51–94 percent of animal protein in the diet in rural areas, and 27–83 percent in urban areas. PNG is the exception, where the large inland population generally has much less access to fish, except for communities living near rivers (Gehrke *et al*., 2011a,b). The high dependence on fish by Pacific communities is a stark contrast with the average global fish consumption of 16–18 kg of fish per person per year (Delgardo *et al*., 2003; FAO, 2010a).

Plans to provide fish for future food security

The vital role that fish plays in food security in many PICTs, and the frequent lack of alternative sources of animal protein (SPC, 2011), has led to plans to provide the fish required in the future (Bell *et al*., 2009; Gillett and Cartwright, 2010). These plans are based on identifying how much fish people should be eating for good nutrition, assessing how much fish they eat now, forecasting how much fish will be needed as human populations increase, and identifying how to provide access to more fish where shortfalls in the productivity of coastal fisheries are projected to occur.

Based on the recommendation from the SPC Public Health Programme that people in the region should eat 35 kg of fish per year to ensure they obtain the protein needed for good health, or to maintain the traditionally greater rates of fish consumption in several PICTs, substantial quantities of fish will be needed across the region in the coming decades, particularly in Melanesia (Table 4). In nine PICTs (American Samoa, Fiji, Guam, Nauru, CNMI, PNG, Samoa, Solomon Islands and Vanuatu), coastal fisheries are not expected to be able to meet the future demand for fish from rapidly growing populations. The gap between the fish required and the fish expected to be available from coastal fisheries (and freshwater fisheries in some cases) (Pratchett *et al*., 2011; Gehrke *et al*., 2011b) will be substantial (Section 3.8). In the remaining 13 PICTs, the area of coral reef per person is expected to be able to supply the recommended quantity of fish per capita well into the future, although there are likely to be problems distributing the fish from remote areas to population centres in some cases (Bell *et al*., 2011c).

Contributions of coastal fisheries and aquaculture to livelihoods

The contribution of coastal fisheries to livelihoods is mainly through the informal economy, where self-employed artisanal and small-scale fishers harvest a wide range of fish species for sale at local markets, or sell fish surplus to household needs (Bell *et al*., 2011c; Pratchett *et al*., 2011). Even so, large numbers of people engage in coastal fisheries for livelihoods across the region. Socio-economic surveys of 4–5 coastal communities in 17 PICTs during the SPC PROCFish Development Project (SPC, 2008b) showed that an average of 47 percent of households derived either their first or second source of income from fishing or selling fish (Table 3). This income can also be used to supplement the diet through the purchase of non-marine protein (FAO, 2010b; SPC, 2011). Aquaculture has also provided large numbers of jobs in rural areas of French Polynesia, Cook Islands and New Caledonia (Table 3).

Plan to increase livelihoods based on coastal fisheries and aquaculture

Few opportunities exist for increasing the number of livelihoods based on coastal demersal fisheries and invertebrates targeted to produce export commodities in most PICTs. Rather, hard decisions are required to reduce fishing to restore the productivity of some coastal stocks, e.g. sea cucumbers (Friedman *et al*., 2008), which can be expected to result in fewer jobs in the short- to medium-term. However, potential exists for more livelihoods to be created by the range of opportunities that exist for enhancing catches of nearshore pelagic fish species by coastal communities, particularly tuna (Section 4).

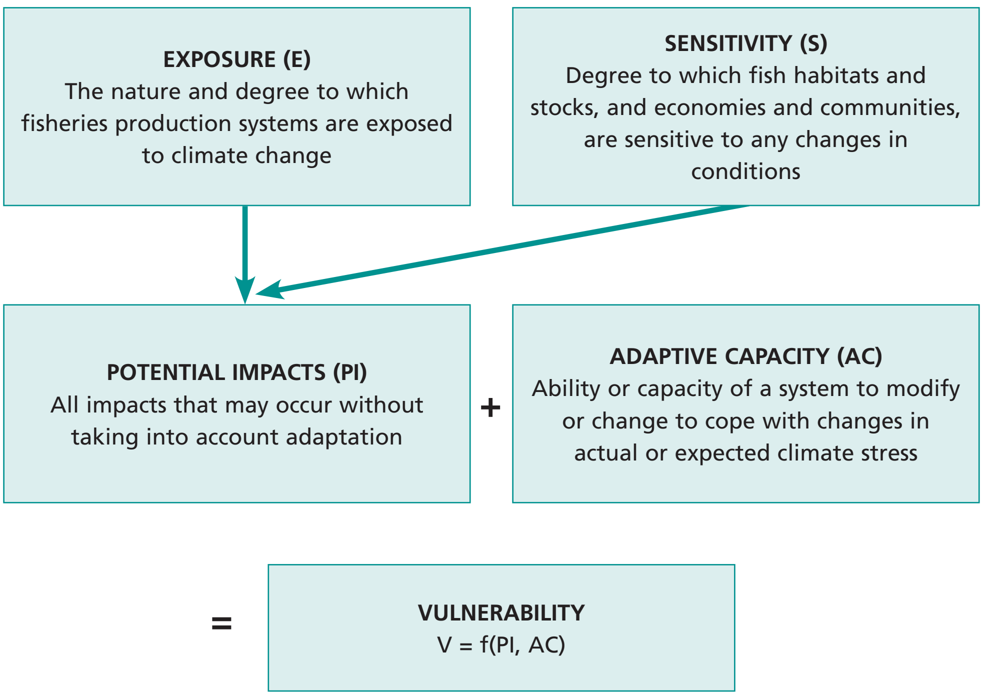
The plans to expand aquaculture in the region (Pickering *et al*., 2011; Bell *et al*., 2011c) are also expected to create more opportunities to earn income, although it is still difficult to identify which commodities will drive these opportunities, or how the new jobs will be distributed among PICTs.

3. Vulnerability of ecological and economic-social systems

The vulnerability of the fish habitats and fish stocks supporting the oceanic, coastal and freshwater fisheries and aquaculture activities of the region was defined using the framework adopted by the Intergovernmental Panel on Climate Change (IPCC) and other initiatives in the fisheries sector (FAO, 2006; Johnson and Marshall, 2007; Allison *et al*., 2009). The framework assesses vulnerability as a function of the character, magnitude and rate of climate variation to which natural and social systems are exposed, their sensitivity and their adaptive capacity (Figure 3).

Exposure is the nature and degree to which a species, ecosystem or society is subjected to significant direct or indirect effects of a changing climate, including variations to natural extremes that exceed known stress thresholds. Sensitivity is the degree to which a species, ecosystem or society is affected, either adversely or beneficially, by exposure to the direct and indirect effects of climate change. Sensitive species, ecosystems and societies are highly responsive to such effects and can be significantly affected by small changes in the magnitude and frequency of climate variables. Assessing sensitivity requires an understanding of the thresholds at which these responses begin to occur, and knowledge about whether these adjustments are likely to be gradual or 'step changes' and whether they are reversible. The consequences of exposure and sensitivity result in a potential impact due to the changing climate. This impact can be modified by the capacity of the species, ecosystem or society to adapt.

FIGURE 3
Model for evaluating vulnerability



Source: Modified from FAO (2006).

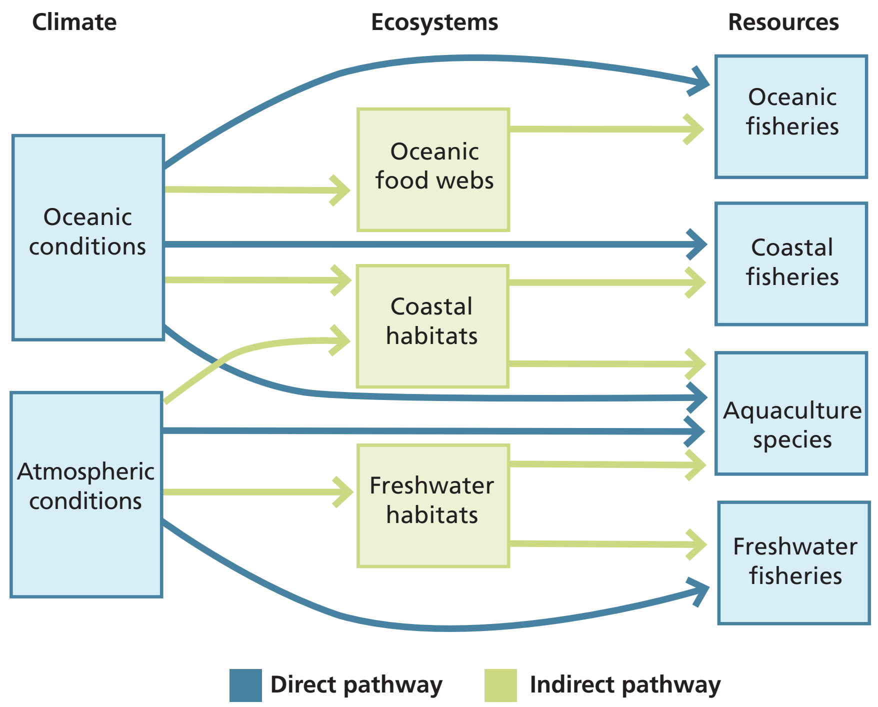
This approach to assessing vulnerability involves integrating scientific information, professional and community knowledge, and expert opinion across all the variables that affect species, ecosystems and societies directly and indirectly to highlight the risks and costs imposed by climate change. Nevertheless, uncertainties occur at a variety of levels, including 1) future greenhouse gas emission trajectories; 2) important processes and relationships at appropriate spatial or temporal scales needed to quantify all parameters adequately in global climate models; and 3) incomplete knowledge of the ecosystems and biological processes that support fisheries and aquaculture (see Bell *et al*., 2011b for more details).

The approach used to assemble the technical information required to assess the exposure of the habitats and stocks underpinning fisheries and aquaculture, and the economies and communities dependent of fisheries and aquaculture, involved:

1. describing the projected changes to atmospheric (surface) climate of the region, and the tropical Pacific Ocean, to determine the direct exposure of the fish and shellfish species used for fisheries and aquaculture (Figure 4);
2. assessing the vulnerability of fish habitats to the projected changes to surface climate and ocean to determine the indirect exposure of fish and shellfish species (Figure 4); and
3. combining this information to evaluate the vulnerability of oceanic, coastal and freshwater fisheries and aquaculture production and then determine the exposure of economies and communities to changes in the contribution of fisheries and aquaculture to economic development, food security and livelihoods.

All projections for surface climate and the ocean in this case study are derived from the Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model data set used for the IPCC's Fourth Assessment Report. These state-of-the-art models,

FIGURE 4
The two pathways used to determine the exposure of the various fisheries resources and aquaculture species in the tropical Pacific to climate change



Source: Bell *et al.* 2011b.

which couple ocean, atmosphere, land and ice models, were applied to simulate the atmosphere and ocean in 2035, 2050 and 2100 under a high (IPCC A2) emissions scenario[8], as described by Bell *et al.* (2011b).

3.1 Projected changes to surface climate

Projections resulting from the multi-model averages for the main features of surface climate are described in detail by Lough *et al.* (2011) and summarized in Table 5.

Surface air temperatures in the tropical Pacific are projected to continue their observed warming trend. By 2035, air temperatures are likely to be 0.5–1.0°C higher than the 1980–1999 average. By 2050, the increase is expected to be 1.0–1.5°C and 2.5–3.0°C by 2100.

There is more uncertainty between the different climate models as to how rainfall patterns will change across the tropical Pacific. However, it seems likely that rainfall will increase in the convergence zones near the equator and decrease in the subtropics. Warming oceans are expected to intensify the hydrological cycle, which is likely to lead to more extreme rainfall events and, given warmer air temperatures, more intense droughts (Table 5). Overall, rainfall in the tropics could increase by 5–20 percent by 2035 and 10–20 percent by 2050/2100.

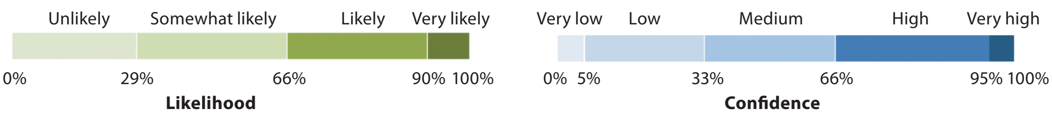
It is still uncertain how the frequency and/or intensity of El Niño-Southern Oscillation (ENSO) events may change in a warming world. Nevertheless, ENSO events are likely to continue to be a major source of interannual climate variability in the tropical Pacific (Lough *et al.*, 2011; Australian Bureau of Meteorology and CSIRO, 2011).

TABLE 5
Summary of projected changes to tropical Pacific surface climate relative to average values for 1980–1999. Recent and projected concentrations of atmospheric carbon dioxide (CO_2) are also shown. Estimates of likelihood and confidence are provided for each projection

Variable		1980–1999 average	Projected change		
			2035	2050	2100
Air temperature (°C)		27.4	+0.5 to +1.0	+1.0 to +1.5	+2.5 to +3.0
Rainfall	Equatorial	n/a	+5 to +20%	+10 to +20%	+10 to +20%
	Subtropics		-5 to -20%	-5 to -20%	-5 to -20%
ENSO events		Interannual variable	Continued source of interannual climate variability		
PDO-decadal variability		Decadal variable	Continued source of decadal modulation in Pacific basin climate and ENSO events		
Tropical cyclones		9	• Total number of tropical cyclones may decrease • Cyclones are likely to be more intense		
Atmospheric CO_2 (ppm)		339–368	400–450	500–600	750–800

Source: Lough *et al.* 2011.

ENSO = El Niño-Southern Oscillation; PDO = Pacific Decadal Oscillation; n/a = data not available.



[8] The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in a continuously increasing global population. Economic development is primarily regionally-orientated, and *per capita* economic growth and technological change are fragmented and slow (Nakicovenic *et al.*, 2000).

There may be fewer tropical cyclones in the region in the future but those that do occur are likely to be more intense. The location of tropical cyclone activity is not projected to change significantly – cyclones are expected to be more frequent and more common between 140°E and 170°E (but extending to 150°W) during La Niña events and less frequent and located mainly between 150°E and 170°W (but extending to 130°W) during El Niño episodes (Lough *et al.*, 2011).

3.2 Projected changes to the tropical Pacific Ocean

The projected changes to the main features of the tropical Pacific Ocean are described in detail by Ganachaud *et al.* (2011) and summarized in Table 6.

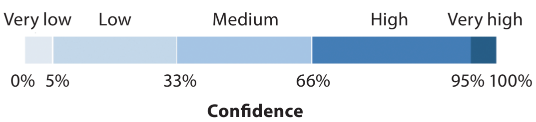
TABLE 6

Summary of observed and projected changes to the main features of the tropical Pacific Ocean. Observed changes are relative to the period 1950–1960. Projected changes are relative to 1980–1999. Estimates of confidence are provided for each projection

Ocean feature	Observed changes	2035	2050	2100
Currents	South Pacific gyre has strengthened	SEC decreases at the equator; EUC becomes shallower; SECC decreases and retracts westward in the upper 50 m		
Sea surface temperature		Projected to increase significantly over the entire region		
		+0.7 to +0.8°C	+1.2 to +1.6°C	+2.2 to +2.7°C
Ocean temperature at 80 m	+0.6 to 1°C since 1950	+0.4 to +0.6°C	+1.0 to +1.3°C	+1.6 to +2.8°C
Warm Pool	Warmer and fresher	Extends eastward; water warms and becomes fresher, and area of warmest waters increases		
Equatorial upwelling	Decreased	Integral transport 9°S–9°N remains unchanged		
Eddy activity	No measurable changes	Probable variations in regions where major oceanic currents change		
Nutrient supply	Decreased slightly in two locations	Decrease due to increased stratification and shallower mixed layer, with a possible decrease of up to 20% under A2 by 2100		
Dissolved oxygen	Expansion of low-oxygen waters	Possible decrease due to lower oxygen intake at high latitudes		
		Possible increase near the equator due to decreased remineralisation		
Ocean acidification		Aragonite saturation (Ω) projected to continue to decrease significantly		
	➢ Ω decreased from 4.3 to 3.9	Ω ~ 3.3	Ω ~ 3.0	Ω ~ 2.4
	➢ Ω horizon rises from 600 to 560 m	~ 456 m	n/a	~ 262 m
	➢ pH decreased from 8.14 to 8.08	~ 7.98	n/a	~ 7.81
Waves	Decreased in far west Pacific; no data elsewhere	Slight increase (up to 10 cm) in swell wave height; patterns depend on ENSO and tropical cyclones		
Sea level	+6 cm since 1960	Projected to rise significantly		
		* +8 cm	+18 to +38 cm	+23 to +51 cm
		** +20 to +30 cm	+70 to +110 cm	+90 to +140 cm
Island effects	Not observed	Probable; undocumented		

Source: Ganachaud *et al.* 2011.

* Projections from the IPCC-AR4, not including any contribution due to dynamical changes of ice sheets; ** projections from recent empirical models (Section 3.3.8.2); SEC = South Equatorial Current; EUC = Equatorial Undercurrent; SECC = South Equatorial Counter Current; ENSO = El Niño-Southern Oscillation; n/a = estimate not available.



Large-scale currents and eddies

The major currents in the tropical Pacific Ocean (Figure 5) are expected to change due to global warming, particularly near the equator. The flow of the South Equatorial Counter Current (SECC) is projected to decrease by about 20 percent in 2035. By 2050, flow of the SECC is expected to reduce by about 30 percent, and by 60 percent by 2100. The South Equatorial Current (SEC) near the equator is projected to decrease in strength by 5 percent in 2035 and by about 10 percent in 2050 and about 20 percent in 2100, with corresponding reductions in SEC transport (volume of water dispersed). The Equatorial Undercurrent (EUC) is expected to increase in strength and transport by 2100, reducing the depth penetration of the SEC. In the Northern Hemisphere, a decrease is projected in the eastern half of the North Equatorial Counter Current (NECC), with a slight decrease in the North Equatorial Current (NEC). Eddy activity can be expected to increase or decrease in association with projected changes in current strength (Ganachaud *et al*., 2011).

Ocean temperature and salinity

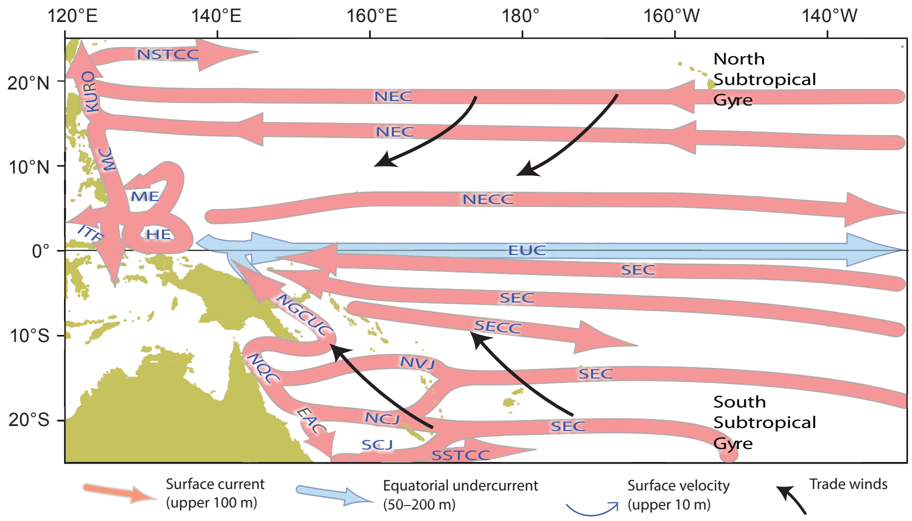
Ocean temperature is expected to continue rising substantially, with higher warming rates near the surface, especially in the first 100 m. Sea surface temperature (SST) is expected to increase 0.7°C by 2035, 1.4°C by 2050 and 2.5°C by 2100. The salinity of the tropical western Pacific Ocean is projected to decrease due to the intensified hydrological cycle (Lough *et al*., 2011). The salinity front associated with the Warm Pool is likely to extend further east by about 2 000 km, while the 29°C isotherm is expected to move further east at the equator. The area of the Warm Pool with SST >29°C is projected to expand by 250 percent by 2035 and >700 percent by 2100.

Nutrient supply

Projected changes to physical features of the ocean that control the supply of nutrients include stratification; maximum depth of the mixed layer during winter; upwelling

FIGURE 5

The main ocean currents in the upper 100 to 200 m of the water column in the tropical Pacific Ocean. Currents shown are: North Subtropical Counter Current (NSTCC); Kuroshio Current (KURO); Mindanao Current (MC); Mindanao Eddy (ME); Halmahera Eddy (HE); North Equatorial Current (NEC); North Equatorial Counter Current (NECC); Equatorial Undercurrent (EUC); Indonesian Throughflow (ITF); New Guinea Coastal Undercurrent (NGCUC); North Queensland Current (NQC); East Australian Current (EAC); North Vanuatu Jet (NVJ); North Caledonian Jet (NCJ); South Caledonian Jet (SCJ); South Equatorial Counter Current (SECC); South Equatorial Current (SEC) and South Subtropical Counter Current (SSTCC)



Source: Ganachaud *et al.* 2011.

or downwelling at a depth of 50 m; and the areas where currents converge. For the region as a whole, stratification is expected to increase by about 10 percent in 2035. Stratification is projected to increase 10–20 percent by 2050, and 20–30 percent by 2100, with the greatest changes in the Warm Pool (Ganachaud *et al*., 2011). The mixed layer depth is projected to be shallower. Minor decreases in upwelling at the equator, and downwelling in adjacent waters, are expected to occur but should not affect the supply of nutrients substantially in the Pacific Equatorial Divergence Province (see below and Figure 6). The major projected change to convergence of currents occurs in the region of the SECC (around 8°S), where the area of eastward flow near the surface is expected to retract west by about 1 500 km by 2100.

Dissolved oxygen

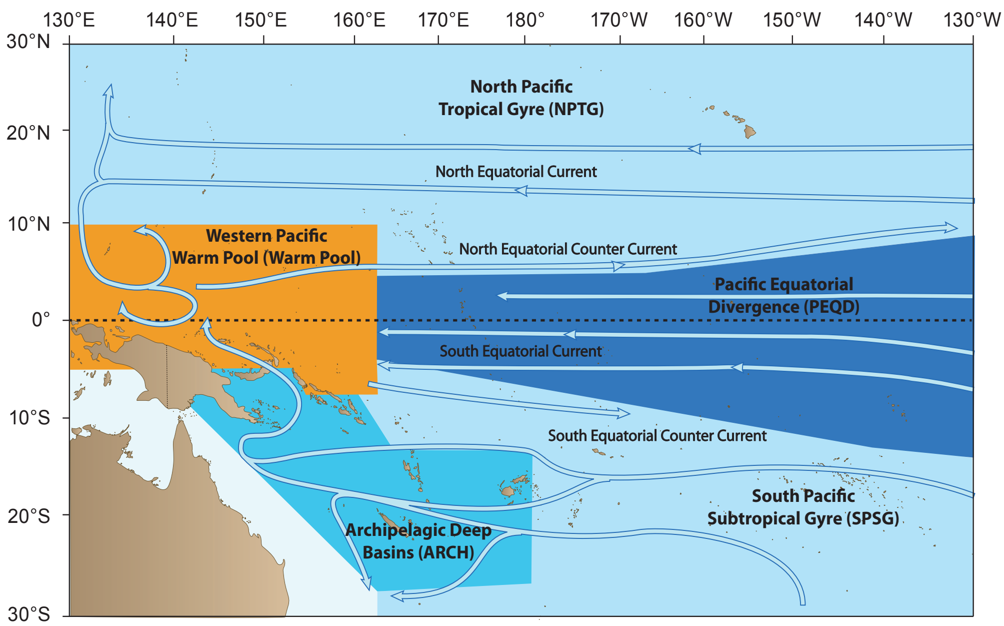
Dissolved oxygen (O_2) is expected to decline in many parts of the tropical Pacific Ocean due to larger-scale processes occurring at higher latitudes. In particular, the increasing temperature and stratification of the ocean at higher latitudes are projected to lead to decreased transfer of O_2 from the atmosphere to the ocean, resulting in lower concentrations of O_2 in the tropical thermocline. The existing low levels of O_2 and suboxic areas in the eastern Pacific are also expected to intensify. In contrast, increased concentrations of O_2 are projected to occur in the equatorial thermocline due to reduced biological production and the associated remineralization/oxidation (Le Borgne *et al*., 2011) within the water masses flowing to the equator.

Ocean acidification

Increases in atmospheric CO_2 are projected to lead to substantial additional acidification of the ocean, reducing the average pH of the ocean by 0.2 in 2050 and 0.3 units by 2100. At such rates of change, aragonite (calcium carbonate) saturation levels in the tropical Pacific Ocean are expected to fall below 3.3 by 2035. The aragonite saturation level is expected to decrease to 2.4 by 2100 (Table 6). The average depth of the aragonite saturation horizon in the region has been 300 m at 8°N, and deeper to the south and to

FIGURE 6

The five ecological provinces of the tropical Pacific Ocean, together with the major currents of the region



Source: Le Borgne *et al.* 2011.

the north (Ganachaud *et al*., 2011). The horizon is projected to become shallower over time, reaching 150 m by 2100.

Sea level

Projections from the IPCC Fourth Assessment Report that sea level will rise by about 50 cm under the A2 emissions scenario by 2100 are now considered to be conservative because they do not include the effects of increased flow from the melting of land ice. Other projections based on historical reconstructions for global sea-level rise, which include the effects of ice melt and thermal expansion, indicate that sea-level rise could be 20–30 cm by 2035, 70–110 cm by 2050 and 90–140 cm by 2100 (see Australian Bureau of Meteorology and CSIRO, 2011 for additional projections of sea level).

3.3 Projected changes to ecosystems and stocks supporting oceanic fisheries

The distributions and abundances of the four tuna species that dominate oceanic fisheries in the region (skipjack tuna, yellowfin tuna, bigeye tuna and South Pacific albacore) are influenced greatly by oceanic conditions.This section summarizes the projected effects of climate change on the main ecosystems (food webs) of the tropical Pacific Ocean (Le Borgne *et al*., 2011) and then uses this information in conjunction with the projected physical and chemical changes to the ocean (Section 2.2) to assess the indirect and direct effects of climate change on the four species of tuna that dominate the oceanic fisheries of the WCPO. Further details of the projected effects on tuna are provided in Lehodey *et al*. (2011).

Ecological structure of the tropical Pacific Ocean

The tropical Pacific Ocean does not provide a uniform habitat for the organisms comprising the food webs for tuna. Rather, the region is divided into five ecological provinces (Longhurst, 2006). These provinces are known as the Pacific Equatorial Divergence (PEQD), Western Pacific Warm Pool (Warm Pool), North Pacific Tropical Gyre (NPTG), South Pacific Subtropical Gyre (SPSG) and Archipelagic Deep Basins (ARCH) (Figure 6).

The borders of these provinces are generally defined by convergence zones of the major surface currents described by Ganachaud *et al*. (2011), and each province has a specific wind regime and vertical hydrological structure (Le Borgne *et al*., 2011). In addition, the locations of PEQD and the Warm Pool change from year to year, depending on prevailing ENSO conditions. Consequently, any analysis of the effects of climate change on the food webs supporting tuna fisheries has to be done in the context of the five ecological provinces.

Projected effects of climate change on the provinces and their food webs

Climate change is expected to alter the surface areas of provinces, except ARCH, which is fixed by definition (Table 7). In particular, the area of PEQD is expected to be reduced by about 25 percent in 2035, 30 percent in 2050 and 50 percent in 2100, the area of the Warm Pool province is projected to increase correspondingly, and SPSG and NPTG are expected to expand towards the poles and to the west.

In addition to the effects of changes in the areas of some provinces, the organisms that comprise the food webs for tuna are expected to respond differently in each province to the projected changes to ocean temperatures, nutrient supply, oxygen levels and ocean acidification (Le Borgne *et al*., 2011). For example, declines in nutrient supply in NPTG and SPSG are expected to reduce the average size and total biomass of phytoplankton, leading to a greater number of trophic links and less efficient food webs.

In contrast, the food web in the PEQD is not projected to be sensitive to decreases in nutrients because the supply of iron is the main factor limiting primary production there. However, possible increases in iron concentrations from a stronger EUC would help overcome the present limitation to primary production and increase the size of phytoplankton, resulting in a more efficient food web with fewer trophic links (Le Borgne *et al*., 2011).

The vulnerability of food webs for tuna in each province to climate change, based on integrating the expected effects of changes to ocean temperatures, nutrient supply, oxygen levels and ocean acidification, are summarized in Table 7.

Vulnerability of tuna to the direct effects of climate change

All four species of tuna are expected to be exposed to changes in ocean circulation and are likely to be sensitive to such changes because currents (and SST) determine the location of spawning grounds, the dispersal of larvae and juveniles, and the distribution of prey. Potential impacts include changes in the location of spawning grounds eastward or to higher latitudes, altered retention of larvae in areas favourable for growth and survival, and shifts in the distribution of prey for juvenile and adult tuna to the east (Le Borgne *et al*., 2011).

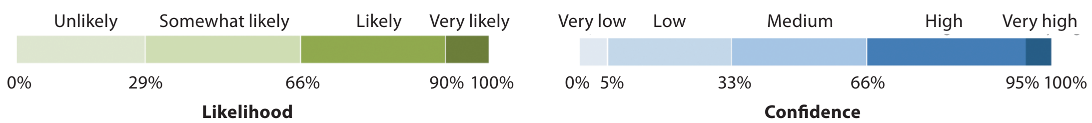
TABLE 7

Integrated vulnerability assessments for tuna foods webs for each of the five ecological provinces in the tropical Pacific Ocean for 2035 and 2100. The likelihood and confidence values associated with these assessments are also shown

Province	Year	Vulnerability	Projected changes
PEQD	2035	Moderate	Decrease in surface area of 27% as western boundary of PEQD moves eastwards from 180° to 170°W. Minor (2%) reduction in zooplankton biomass. No direct effect of higher SST, and lower O_2 and pH, on biomass or composition of plankton.
	2100	High	Decreases in surface area of 50% and movement of boundary to 160–150°W. A 4% increase in NPP and 6% decrease in biomass of zooplankton. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
Warm Pool	2035	Moderate	Increase in surface area eastwards by 21%, with a 7% reduction in NPP and 6% decrease in biomass of zooplankton throughout the water column. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
	2100	High	Increase in surface area eastwards by 48%, with a 9% reduction in NPP and 10% decrease in biomass of zooplankton throughout the water column. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
NPTG	2035	Low	Surface area increases limited to 1% as the province extends to the north. NPP decreases by 5% and zooplankton biomass declines by 4%. No direct effect of higher SST and O_2, or lower pH, on biomass or species composition of plankton.
	2100	Moderate	Increase in surface area stabilises at an increase of 1% but NPP decreases greatly (22%) and biomass of zooplankton declines by 18%. No direct effect of higher SST and O_2, or lower pH, on biomass or species composition of plankton.
SPSG	2035	Low	Surface area increases by 7%. NPP decreases by 5% and biomass of zooplankton declines by 4%. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
	2100	Low-Moderate	Surface area increases by 14% and extends poleward, with a 6% reduction in NPP and 10% decrease in biomass of zooplankton due to deepening of the thermocline. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
ARCH	2035	Low	No change in surface area. A reduction in NPP of 8% and a 6% decrease in biomass of zooplankton due to deepening of the thermocline. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.
	2100	Moderate	No change in surface area. Greater (33%) reduction in NPP and a 26% decrease in biomass of zooplankton due to deepening of the thermocline. No direct effect of higher SST, and lower O_2 and pH, on biomass or species composition of plankton.

Source: Le Borgne *et al.* 2011.

SST = sea surface temperature; O_2 = dissolved oxygen percentage saturation at 300 m; PEQD = Pacific Equatorial Divergence; Warm Pool = Western Pacific Warm Pool; NPTG = North Pacific Tropical Gyre; SPSG = South Pacific Subtropical Gyre; ARCH = Archipelagic Deep Basins.



All species of tuna are also likely to be highly exposed to increases in surface and sub-surface temperature and will be sensitive to these changes because temperature regulates metabolism and development, and limits activity and distribution. Tuna are most sensitive to changes in temperature during their larval and juvenile life stages but have wider temperature tolerances as they mature. Ocean warming may affect the distribution of tuna by changing spawning locations and success, and accessibility to feeding areas due to increased stratification of the water column.

Tuna will be highly exposed to possible reductions in dissolved oxygen. Because O_2 is critical for maintaining metabolic rate and mobility, tuna are expected to be sensitive to these changes. However, sensitivity to O_2 availability and to lethally low levels of O_2 varies among tuna species – skipjack and albacore are less tolerant to low O_2 concentrations than yellowfin, whereas bigeye is the most tolerant species. Changes in O_2 in subsurface waters are expected to have limited impact on skipjack tuna, which inhabit the surface layer. However, greater impacts are possible for yellowfin and albacore that swim regularly between the surface and subsurface, and for bigeye which descends to deeper layers. Any decrease in O_2 concentrations at mid- to high-latitudes may limit the extension of tuna habitat into more temperate areas.

Tuna species will also be exposed to increased acidification of the ocean and are likely to be sensitive because ocean chemistry affects blood pH, otolith formation and ocean acoustics. The potential physiological impacts associated with compensating for acidosis (lower blood pH), may involve lower growth rates and egg production, and impaired acoustic ability of tuna to assess their physical and biological environment and detect prey and predator species. Acidosis could also lead to a narrowing of the optimal thermal performance range and, consequently, altered resistance, metabolic rate and behaviour of tuna. Ocean acidification could also affect the behaviour of tuna larvae, reducing survival.

All four tuna species are expected to adapt fairly easily to the changing conditions in the ocean, although their ability to adapt to ocean acidification is still unknown. Both juvenile and adult tuna are highly mobile and can follow their preferred temperature range and prey, as presently observed during the different phases of ENSO (Lehodey *et al*., 1997). Tuna can adapt to reductions in dissolved oxygen by changing the ocean layers they use and are expected to be able to seek out suitable conditions for spawning and productive feeding areas within their tolerances to dissolved oxygen. Nevertheless, the projected changes to currents, ocean temperatures and O_2 are expected to have effects on the distribution and catchability of tuna.

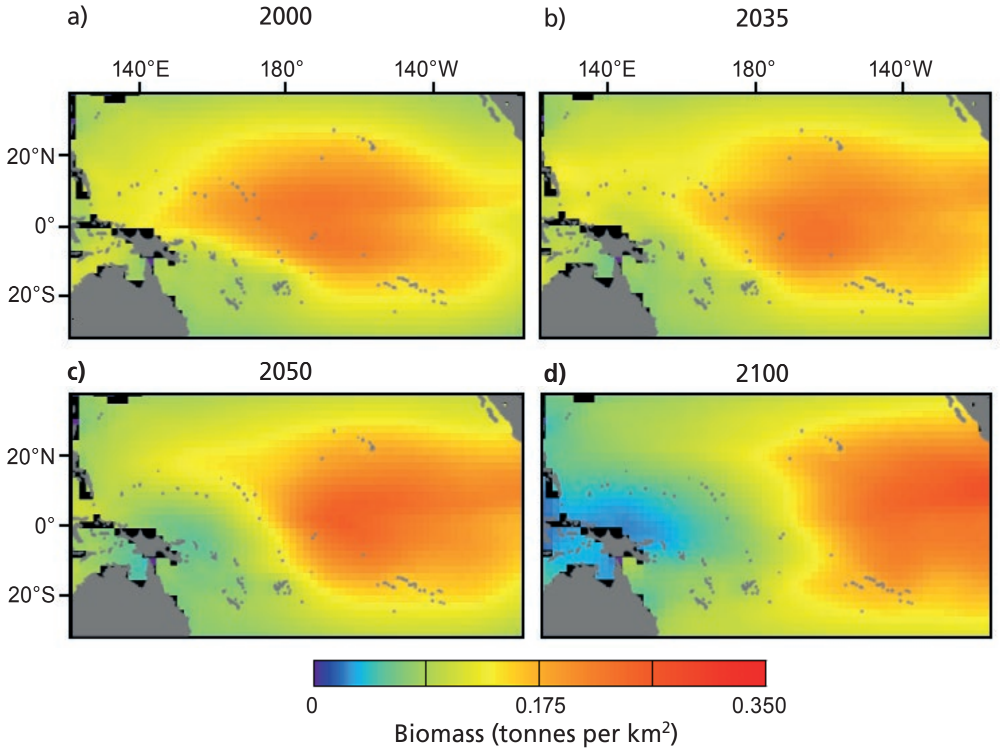
Vulnerability of tuna to the indirect effects of climate change

Tuna are eventually expected to be exposed to declines in primary productivity in much of the tropical Pacific Ocean due to increased stratification of the water column (Section 3.2). The reduced supply of nutrients is likely to change the composition of food webs for tuna in all provinces, as described above. Tuna are expected to be particularly sensitive to any decrease in the productivity of the micronekton they feed on because of their high energy requirements for rapid growth, great rates of egg production, and constant and fast swimming activity. Any mismatches between periods of high primary productivity and spawning events, and between the distribution of larvae and their zooplanktonic food, are expected to affect the survival of larvae and subsequent recruitment success of tuna.

The projected shift of the convergence between the Warm Pool and PEQD to the east (Table 7) would change the location of the best feeding grounds for the abundant skipjack tuna. The projected reductions in the productivity of food webs in the Warm Pool, NPTG and SPSG are likely to result in lower catches of tuna in those provinces.

FIGURE 7

Projected estimates of total biomass (tonnes per km^2) of skipjack tuna based on average (1980–2000) fishing effort, in (a) 2000, and by (b) 2035, (c) 2050 and (d) 2100



Source: Lehodey *et al.* 2011.

Future tuna catches

Preliminary modelling indicates that the distribution of skipjack tuna is eventually likely to shift eastward and to higher latitudes (Figure 7), primarily as a result of 1) increasing ocean temperature making the western equatorial Pacific unsuitable for spawning; and 2) the contraction of the productive convergence zone between the Warm Pool and the PEQD to the east. In the shorter term, however, the preliminary modelling indicates that catches of skipjack are likely to increase across the region by 2035. The increases are expected to be greater for PICTs in the eastern Pacific than in the western Pacific (Table 8). By 2050, catches for the western Pacific are projected to decrease and return to the average levels for the region in 1980–2000. In

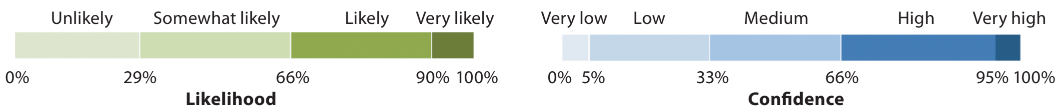
TABLE 8

Projected percentage changes in average catches of skipjack and bigeye tuna for the western and eastern Pacific by 2035, 2050 and 2100, relative to 1980–2000 levels (note that results are based on preliminary modelling only). The likelihood and confidence values associated with these projections are also shown

	West[a]			East[b]		
	2035	2050	2100	2035	2050	2100
Skipjack tuna	+10	0	-20	+30 to 35	+40 to 45	+25 to 30
Bigeye tuna	0 to -5	-10 to -15	-30 to -35	0 to +5	0 to -5	-15 to -20

Source: Lehodey *et al.* 2011).

a = 15°N–20°S and 130°–170°E; b = 15°N–15°S and 170°E–150°W.



contrast, average catches in the eastern Pacific are expected to increase by >40 percent (Table 8).

By the end of the century, average catches of skipjack from the western Pacific are estimated to decline by >20 percent but still remain higher than those from 1980–2000 in the east, albeit at lower levels than in 2050. Across the entire region, total skipjack catch is projected to decrease by 7.5 percent by 2100 (Table 8).

For bigeye tuna, small decreases in catch (usually <5 percent) are projected to occur across much of the region by 2035. The magnitude of the reduced catches is projected to increase to 5–10 percent by 2050 and 10–30 percent by 2100 for many PICTs (Table 8).

3.4 Projected changes to ecosystems and stocks supporting coastal fisheries

The total coastal subsistence and commercial fish catch of 155 000 tonnes per year is estimated to contribute USD 272 million to GDP (Gillett, 2009). This section summarizes the projected effects of climate change on the main ecosystems that support coastal fisheries in the tropical Pacific – coral reefs, mangroves, seagrasses and intertidal flats – and then uses this information in conjunction with the projected physical and chemical changes to the ocean (Section 3.2) to assess the indirect and direct effects of climate change on the three main coastal fisheries categories of the region (Section 2.7). Further details of the projected effects of climate change of coastal fish habitats and stocks are provided in Hoegh-Guldberg *et al.* (2011), Waycott *et al.* (2011) and Pratchett *et al.* (2011).

Projected effects on coral reefs

Coral reefs will be highly exposed and sensitive to the projected increases in SST (Section 3.2), with the symbiotic relationship between coral hosts and symbiotic dinoflagellates (*Symbiodinium*) breaking down under extended periods of thermal stress. The impact of thermal stress – known as coral bleaching – has been positively correlated with periods when SST exceeds the summer maxima by 1–2°C for 3–4 weeks or more, especially during strong El Niño events (Hoegh-Gulberg *et al.*, 2011). Varying thermal sensitivity of some coral genera is expected to lead to progressive dominance by heat-tolerant species. The capacity for some corals to adapt to warmer waters by increasing the more temperature-tolerant *Symbiodinium* in their tissues is expected to provide added tolerance only up to increases of 1.5°C. However, this potential adaptive mechanism (called symbiont shuffling) also results in slower growth rates and is unlikely to protect reefs from the severe and repeated damage projected to occur due to rapid warming of the tropical Pacific Ocean.

Corals are likely to be moderately exposed to increases in solar radiation due to changes in cloud cover associated with projected changes to the hydrological cycle (Section 3.1). Corals are sensitive to increases in photosynthetically active radiation (PAR) and ultraviolet radiation (UVR). Higher levels of PAR can exacerbate coral bleaching and greater UVR can damage cellular components such as DNA. Corals have some ability to adapt to high and variable solar radiation through photoacclimation over a period of 5–10 days, although they remain physiologically stressed.

The decreases in pH, and therefore aragonite saturation levels, described in Section 3.2 pose severe threats to coral reefs because corals are sensitive to reductions in the availability of the calcium carbonate they need to build their skeletons (Hoegh-Guldberg *et al.*, 2007; 2011). The ability of corals and other marine calcifying organisms to maintain a positive reef carbonate balance is expected to fall into deficit when atmospheric concentrations of CO_2 exceed 450 ppm. Substantial decreases in calcification can be expected to result in more fragile and degraded reef frameworks. There is little evidence of calcifying organisms adapting to the lower concentrations of carbonate ions projected to occur under ocean acidification during the 21st century.

Coral reefs will be exposed to any increases in cyclone intensity (Section 3.1), and are highly sensitive to the local physical damage caused by cyclones, particularly in shallow reef environments. Full recovery from the effects of cyclones can take 10–50 years. Coral communities regularly exposed to cyclones are usually dominated by species with stout growth forms, *Acropora* and other fast-growing species.

However, these reefs have had thousands of years to adapt and such adaptation is likely to be affected by the increased stress to corals from more frequent bleaching and the effects of ocean acidification on formation of coral skeletons. But no level of adaptation protects coral reefs from the severe damage caused by more intense (category 4 or 5) cyclones.

The coral reefs around high islands will be more highly exposed to the runoff after heavy rainfall (Section 3.1). Corals are sensitive to the higher turbidity and nutrient enrichment, and lower salinity, caused by runoff. Increased sediment and nutrient loads impede photosynthesis by the symbiotic dinoflagellates and create more favourable conditions for the epiphytic algae that compete with corals. Negative impacts on coral growth, recruitment and recovery can be expected after heavy runoff. Some corals can photo-acclimate to lower light levels in turbid waters (with turbidity potentially protecting them from bleaching) and some species are more tolerant of higher sedimentation. However, these adaptations come at an energy cost and such corals may no longer form structurally complex reefs.

Coral reefs are also expected to be exposed to the projected increases in sea level (Section 3.2). However, their sensitivity will depend on the rate and magnitude of sea-level rise, as well as the influence of other factors on coral growth rate. In some places, sea-level rise may increase flushing, improving coral growth in places subject to runoff. Overall, however, the effects of increasing SST and ocean acidification are likely to make corals more sensitive to sea-level rise.

Changes in ocean circulation, upwelling and nutrient supply (Section 3.2) are also expected to alter the conditions required for reef formation. Corals are highly sensitive to reductions in dispersal of larvae (connectivity) and net primary productivity. Changes in currents will have potential impacts on the replenishment rate of coral reef communities. Reductions in net primary production due to increased stratification (Section 3.3) are expected to exacerbate the reductions in coral growth caused by increased bleaching and reduced aragonite concentrations.

When the various effects of climate change on coral reefs summarized in Table 9 are integrated, coral reef habitats are projected to continue to decline progressively for the remainder of the century (Hoegh-Guldberg *et al*., 2007; 2011) (Table 10). The degradation of coral reefs and decline in coral cover will create more substrata for the growth of macroalgae, with the result that these plants will be more dominant on the reefs of the future (Table 10).

The changes in relative cover of live coral and macroalgae will cause fundamental changes to the habitats provided for demersal fish species and invertebrates (Figure 8). Management of other human pressures on reefs, such as reduction of sediment and nutrient delivery from catchments, will assist reefs to tolerate increasing SST and ocean acidification and recover from disturbances. Strong management is expected to limit the loss of coral and proliferation of macroalgae under both scenarios by 2035 and 2050 but could have little effect by 2100 (Table 10).

Projected effects on mangroves

Respiration and productivity of mangroves are likely to improve as atmospheric concentrations of CO_2 increase, resulting in greater productivity of mangroves, and changes to the species composition of mangrove communities. Mangroves are also projected to be exposed to ocean acidification but are not expected to be sensitive.

TABLE 9

Summary of vulnerability of coral reefs, mangroves and seagrasses in the tropical Pacific to projected changes in surface climate and the ocean

	SST*	Solar radiation	Ocean chemistry	Cyclones and storms	Rainfall patterns	Sea level**	Nutrients
Coral reefs							
2035	Very high	Low	Very high	Moderate	High	Low-moderate	Moderate
2050	Very high	Low	Very high	Moderate	High	Low-moderate	Moderate
2100	Very high	Low	Very high	Moderate	High	Low-moderate	Moderate
Mangroves							
2035	Very low	Low	Very low	Moderate	Low	High	Low
2050	Very low	Low	Very low	Moderate	Moderate	Very high	Low
2100	Very low	Low	Very low	Moderate	Moderate	Very high	Low
Seagrasses							
2035	Moderate	Moderate	Very low	Moderate	Moderate	Low	Low
2050	Moderate	Moderate	Very low	Moderate	Moderate	Moderate	Low
2100	High	High	Very low	High	High	Moderate	Moderate

Source: Hoegh-Guldberg *et al.* 2011; Waycott *et al.* 2011.

* SST = sea surface temperature; ** range of vulnerability reflects the significant uncertainty regarding the rate of sea-level rise.

TABLE 10

Estimated projected changes in the percentage cover of live coral and macroalgae on reefs in 2035, 2050 and 2100 (relative to 2010) under poor and strong management. The expected remaining cover (%) of coral and macroalgae is also shown, together with the likelihood and confidence values associated with these projections

Year	Management	Coral cover		Macroalgal cover	
		%	% decrease	%	% increase
2035	Strong	15–30	25–65	40	130
	Poor	15	65	40–60	130–200
2050	Strong	10–20	50–75	50	> 150
	Poor	< 5	> 85	80	> 250
2100	Strong	< 2	> 90	> 95	> 300
	Poor	< 2	> 90	> 95	> 300

Source: Hoegh-Guldberg *et al.* 2011.

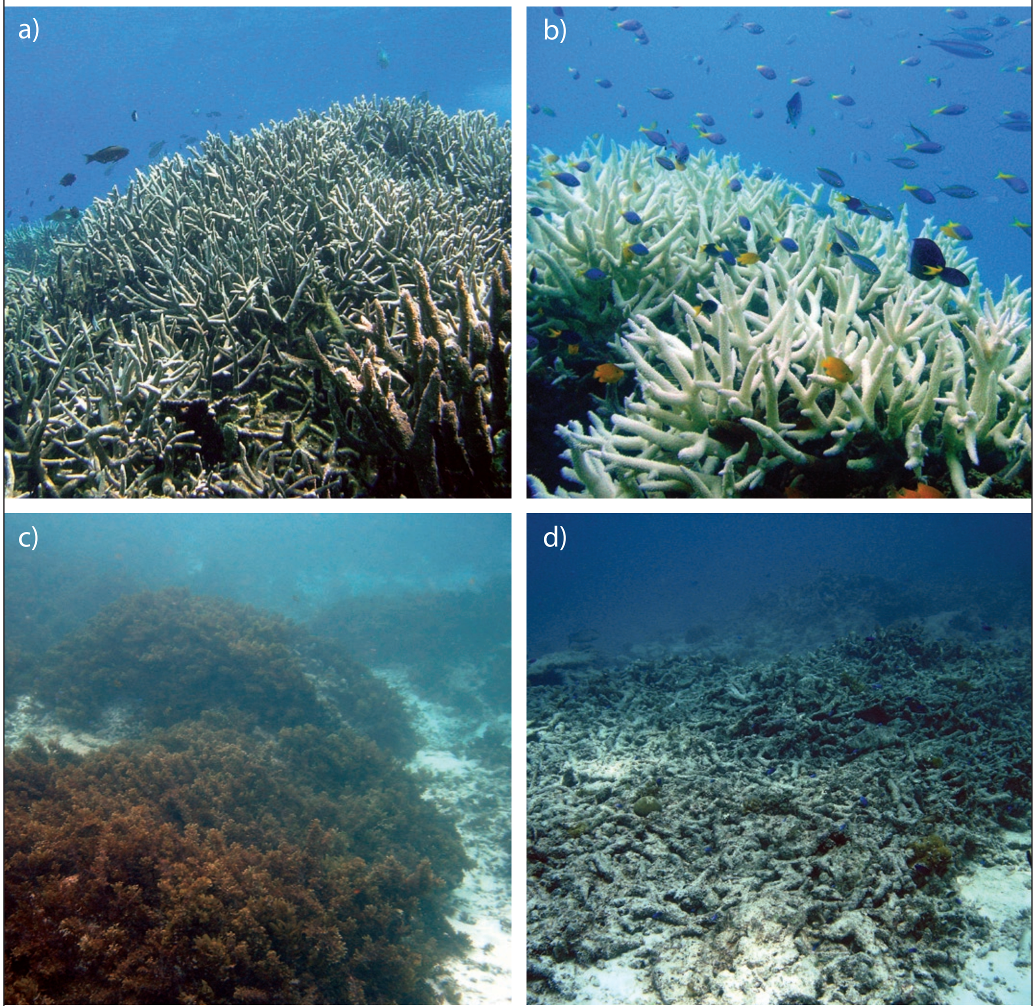
Unlikely Somewhat likely Likely Very likely
0% 29% 66% 90% 100%
Likelihood

Very low Low Medium High Very high
0% 5% 33% 66% 95% 100%
Confidence

Mangroves are expected to be highly exposed to increases in air and sea surface temperatures (Sections 3.1 and 3.2). The trees are likely to be moderately sensitive to the projected increases in temperature through their increased respiratory demands. Potential impacts include greater mortality of young seedlings, and development of more silt roots and smaller leaves in some species. Mangroves have limited capacity to adapt to increasing SST but should be able to adapt to higher air temperatures by reducing the apertures of their leaf stomata to cope with water loss induced by increased evaporation under heat stress.

FIGURE 8

Changes in the state of coral reef ecosystems caused by climate-induced coral bleaching. (a) Coral-dominated and structurally complex coral reef habitats typical of many reefs today; (b) bleached coral; (c) bleached reefs overgrown with algae; and (d) rubble banks formed when dead reefs collapse, removing the structurally complex habitat required for colonisation of many species of fish



Source: Pratchett *et al*. 2011.

Mangroves are also expected to be highly exposed to projected changes in rainfall (Section 3.1). The trees are moderately sensitive to the resulting changes in soil salinity, freshwater saturation and sediment delivery. Mangroves are likely to grow better where increased rainfall lowers salinities, except in locations where the soil is frequently saturated with freshwater because root growth is likely to be retarded, especially in seedlings. Decreased rainfall in the subtropics has the potential to cause more significant impacts – increases in soil salinity affect plant growth, reduced sediment delivery will inhibit vertical accretion, and flowering and fruiting will be limited. Mangroves can adapt to decreasing rainfall by using water more efficiently and reducing transpiration rates to avoid water loss.

Reduced rainfall in the subtropics (Section 3.1) will expose mangroves to more solar radiation. Mangroves are sensitive to increases in light. When coupled with lower rainfall, increased light levels have the potential to overheat mangroves and damage plant cells. Mangroves have limited ability to adapt to higher solar radiation.

More variable rainfall patterns will also expose mangroves to changes in nutrient supply. Mangroves are sensitive to nutrient levels – a good supply of nutrients fertilizes mangroves and increases their growth, whereas reductions in nutrient delivery due to low rainfall limit growth and affect the species composition of mangrove communities. The potential beneficial impacts of increased nutrients will be most evident when coupled with increases in air temperature and CO_2. Adaptations of mangroves to changes in nutrient levels are expected to be most evident at the community level, with different species dominating under particular nutrient conditions.

Exposure of mangroves to any increases in cyclone intensity will have severe consequences because cyclones damage foliage, desiccate plant tissues, and increase evaporation rates and salinity stress. More powerful wave surge during cyclones also erodes sediments on the seaward edge of mangroves and reduces the stability of plants. Mangrove species have different tolerances to cyclone damage – some species can resprout from dormant buds, whereas re-establishment of other species depends largely on recruitment of seedlings from adjacent undamaged areas.

The projected rise in sea level is expected to expose mangroves in low-lying areas to permanent inundation and trees at higher elevations to more frequent inundation. The sensitivity of mangroves is expected to be high to very high depending on the rate and magnitude of sea-level rise. More frequent inundation by sea water has critical implications for plant growth, respiration and survival. The ability of mangroves to migrate landward as sea level rises is an important adaptation, but will depend on: 1) topography, 2) the rate of sea-level rise, 3) hydrology, 4) sediment composition, and 5) competition with non-mangrove species in landward areas. There is concern that the capacity of mangroves to migrate landward may not be able to keep pace with the projected accelerated rate of sea-level rise. In many places, steep terrain and existing infrastructure (e.g. roads) will prevent any migration.

Mangroves are expected to be most vulnerable to sea-level rise, but also to any possible increases in cyclone intensity and changes in rainfall (Table 9). When these effects are integrated, they are projected to reduce the area of mangrove habitat in PICTs significantly by 2035, with major declines (>50 percent) occurring by 2050 (Table 11).

Projected effects on seagrasses

Seagrasses, like mangroves, will be exposed and sensitive to increasing CO_2 concentrations and ocean acidification. Seagrasses are expected to benefit from higher CO_2 concentrations through increased productivity, biomass and reproductive output resulting from faster rates of photosynthesis. Seagrasses are unlikely to be sensitive to ocean acidification because the plants currently experience greater variations in pH on a daily basis.

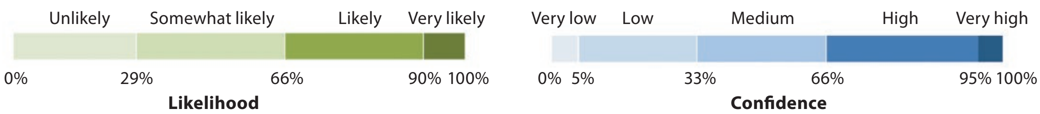
Intertidal and subtidal seagrasses are expected to be highly exposed to increases in air temperature and SST and will be highly sensitive to these changes because chronic elevated SST increases respiratory demand that can exceed photosynthesis and affect

TABLE 11

Projected loss of mangrove and seagrass habitat in the tropical Pacific by 2035, 2050 and 2100, relative to 2010. The likelihood and confidence values associated with these projections are also shown

Year	Mangrove area (%)	Seagrass area (%)
2035	-10 to -30	< -5 to -20
2050	-50 to -70	-5 to -35
2100	-60 to -80	-10 to -50

Source: Waycott *et al.* 2011.



growth and survival. The potential impacts of increased SST include changes in species composition, relative abundance and distribution of seagrasses, as well as acute 'burn off' during short-term temperature spikes. The high light requirements of many tropical seagrass species and overall respiration demand will limit their ability to adapt to increasing SST by colonizing deeper areas. Indeed, this form of adaptation is unlikely to occur in the tropics where seagrasses are expected to be exposed to reductions in solar radiation due to more cloudy days and turbidity associated with increased rainfall (Section 3.2). Seagrasses are sensitive to decreases in light, because the related declines in photosynthesis affect growth rates and eventually the species composition of seagrass communities. Where reduced light persists for long periods, the area of seagrass habitat decreases. High levels of UV light reduce production of chlorophyll in seagrass tissues and enhance production of pigments, causing 'reddening' of plant leaves.

The effects of reduced light for plants at the deeper margins of seagrass habitats are likely to be compounded by sea-level rise. The potential impacts in such locations are expected to be losses in seagrass area or changes in species composition. Seagrasses growing along the deeper margins of meadows are at the limit of their light tolerance and are unlikely to be able to adapt to further light reductions. In some intertidal and shallow subtidal areas, seagrasses are expected to adapt to rising sea levels by growing landward, provided the newly inundated sediments are suitable.

Increased rainfall in the tropics will also expose seagrasses to changes in nutrients, sedimentation, salinity and physical scouring. Limited increases in nutrients are expected to enhance seagrass growth. However, excessive nutrient concentrations promote growth of epiphytes on seagrass leaves, blocking light and retarding seagrass growth. On balance, the potential impacts of increased nutrients are likely to be generally beneficial but seagrasses have little capacity to adapt to heavy growth of epiphytes. Seagrasses have low adaptive capacity to high levels of sediment deposition and scouring. However, some species are more tolerant of low salinity and such species would be expected to become more prevalent.

Seagrasses in intertidal and shallow subtidal areas will also be exposed to any increases in cyclone intensity. Seagrasses are particularly sensitive to the physical effects of storm surge associated with cyclones, which strip leaves and uproot plants and smother plants with sediments. Small species of seagrass suffer more damage from cyclones than larger species which have rhizomes buried deeper in the sediment. On the other hand, smaller species have the capacity to recover rapidly provided propagules are available from nearby meadows.

Overall, seagrasses are expected to be most vulnerable to increasing SST, decreasing solar radiation, changing rainfall patterns and possible increases in cyclone intensity (Table 9). The combination of these effects could reduce seagrass area within PICTs by up to 20 percent by 2035 and by as much as 50 percent by 2100 (Table 11).

Projected effects on intertidal flats

Intertidal flats and the productive benthic microalgae communities that they support are expected to be highly exposed to sea-level rise. Intertidal flats are likely to be highly sensitive to rising sea level where there is little scope for expansion landward due to barriers. The potential impacts include considerable losses of intertidal habitat, and the associated species that are not adapted to live subtidally. Consequently, the areas of intertidal flats in PICTs are expected to decrease progressively over the course of this century. It is not possible to estimate the area likely to be lost due to poor baseline data for this habitat in the region.

Vulnerability of coastal fisheries to the direct effects of climate change

Demersal fish and invertebrate species are expected to be highly exposed to projected increases in SST (Section 3.2), and are likely to be sensitive to these changes because temperature regulates metabolism and development, and influences activity and distribution. Demersal fish and invertebrate species are relatively tolerant of short-term changes in temperature because they are exposed to such variation during tidal cycles and during different seasons. However, all species have a thermal optimum and when this threshold is exceeded, increased metabolic rate and oxygen demand may interfere with their reproduction, recruitment and growth. Many demersal fish and invertebrate species may be able to adapt through settlement of larvae in places outside their existing range where temperatures remain below the thermal optimum threshold. However, such adaptation will be difficult for species that depend on coral reefs if no reefs are available within the optimal temperature range.

Demersal fish and invertebrate species are expected to be exposed to ocean acidification which is projected to result in decreases in aragonite saturation levels (Section 3.2). In particular, molluscs are expected to be highly sensitive to the effects of lower aragonite saturation levels, which will affect their ability to construct protective shells. The main potential impact is expected to be greater predation on molluscs with thinner shells. The sensory ability of larval and postlarval demersal fish can also be impaired by the reduced pH of sea water. This can lead to a loss of the ability to navigate to reefs, distinguish beneficial settlement sites and detect and avoid predators. Demersal fish and invertebrate species are likely to lack the genetic variation necessary for rapid adaptation to changes in seawater chemistry because ocean pH has changed little over the past 800 000 years.

Demersal fish and invertebrate species are projected to have low vulnerability to sea-level rise, changes to rainfall and solar radiation, and possible increases in cyclone and storm intensity. These variables are expected to have the most influence on these species, indirectly, through their effect on coastal habitats (see below).

The vulnerability of the nearshore pelagic component of coastal fisheries, which is dominated by tuna in several PICTs (Pratchett *et al*., 2011), is expected to be similar to the vulnerability of oceanic fisheries (Section 3.3).

Vulnerability of coastal fisheries to the indirect effects of climate change

Demersal fish and invertebrate species are expected to be indirectly exposed to climate change through the projected changes to the coral reefs, mangroves, seagrasses and intertidal flats. These coastal fisheries species are likely to be highly sensitive to changes in the quality of the food and shelter they need caused by degraded habitats. The potential impacts include reduced diversity and abundance of demersal fish and invertebrates as their food resources decline, and increased rates of mortality (predation) as structurally complex habitat (shelter) is lost. Specialist fish species that depend directly on live coral for food and shelter are likely to experience greater impacts than generalist species, which can switch to using alternative resources. Generalist demersal fish species such as the carnivorous snappers (*Lutjanidae*) and emperors (*Lethrinidae*) are expected to adapt because they already use a range of habitats. Nevertheless, significant changes in species composition of demersal fish associated with coral are expected. In particular, the proportions of herbivorous parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*), and rabbitfish (*Siganidae*) are likely to increase as the percentage cover of live corals declines and the cover of macroalgae increases.

The nearshore pelagic fish component of coastal fisheries is not expected to be affected strongly by changes to coral reefs, mangroves, seagrasses and intertidal flats because these oceanic fish species have a low dependence on coastal fish habitats.

Future catches from coastal fisheries

Coastal fisheries species are projected to be most vulnerable to increasing SST, ocean acidification, changes to ocean circulation and habitat degradation. The important demersal fish component of coastal fisheries (Table 12) is expected to have a low vulnerability to the combined effects of the projected increases in SST, ocean acidification, changes in currents and alterations to habitats by 2035. However, the vulnerability of this component is expected to increase to moderate by 2050 and to high by 2100. Overall, the production of demersal fish is estimated to decrease by < 5 percent by 2035 due to the effects of climate change. However, production is expected to be reduced by 20 percent by 2050 and by 20–50 percent by 2100.

The vulnerability of nearshore pelagic fish, which comprise about 30 percent of the coastal fisheries catch (Table 12), is likely to differ across the region due to the different contributions of tuna to this catch in the east and the west, and the projected shift in distribution of tuna to the east (Section 3.3). In the west, nearshore pelagic fish are expected to have little or no vulnerability to climate change by 2035, increasing to low to moderate in 2050 and to moderate by 2100. In the east, the net effect of climate change on nearshore pelagic fish is expected to be positive for the remainder of the century (Table 12).

Invertebrates are estimated to have little or low vulnerability to climate change by 2035, increasing to low to moderate by 2050 and moderate to high by 2100. Decreases in productivity of invertebrates is also expected to be lower than for demersal fish (Table 12).

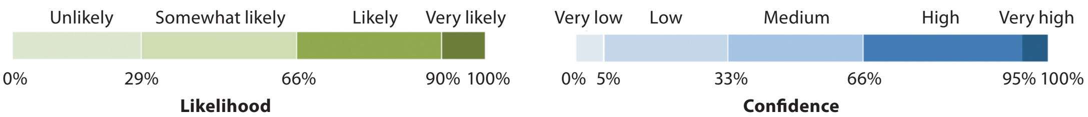
TABLE 12

Vulnerability (V) and projected changes in production (P) of the three main categories of coastal fisheries and total coastal fisheries production, in Pacific Island countries and territories, by 2035, 2050 and 2100. Note that the availability of nearshore pelagic fish is expected to increase in the eastern part of the region. The likelihood and confidence values associated with these projections are also shown

Variable			Coastal fisheries category: Demersal fish	Nearshore pelagic fish		Shallow subtidal and intertidal invertebrates	Total coastal fisheries***	
Present contribution to coastal fisheries production			56%	28%		14%		
				West*	East**		West*	East**
Vulnerability and projected change in production	2035	V	L	nil	L	nil	nil[a]	nil[a]
		P	-2 to -5%	nil	+15 to +20%	nil	Negligible	Negligible
	2050	V	M	L-M	L	L	M	L
		P	-20%	-10%	+20%	-5%	-10 to -20%	-5 to -10%
	2100	V	H	M	L	L-M	M-H	M
		P	-20 to -50%	-15 to -20%	+10%	-10%	-20 to -35%	-10 to -30%
Major impacts			Habitat loss, and reduced recruitment due to ⇧SST and ⇩currents	Reduced production of zooplankton in food webs for non-tuna species and changes in distribution of tuna		Declines in aragonite saturation due to ocean acidification		

Source: Pratchett *et al.* 2011.

* 15°N–20°S and 130°–170°E; ** 15°N–15°S and 170°E–150°W; *** assumes that the proportions of the four coastal fisheries categories remain constant; a = nil or very low vulnerability; ⇧ = increasing sea surface temperature; ⇩ = reduced currents; L = low; M = moderate; H = high.



Although demersal fish dominate the production of coastal fisheries, the overall decreases in total coastal fisheries production are tempered by the projected changes to catches of nearshore pelagic fish, which consist of a high proportion of tuna in many PICTs (Table 12). When the different projected changes in production of the three main components of coastal fisheries due to climate change are combined, negligible reductions in total coastal fisheries catch are expected by 2035 in both the western and eastern parts of the region (Table 12). By 2050 in the west, a decrease in total production of 10–20 percent is expected and by 2100 a decrease of 20–35 percent is projected to occur. Due to the expected shift in distribution of tuna, the decreases in total coastal fisheries production in the east are expected to be limited to 5–10 percent by 2050 and 10–30 percent by 2100 (Table 12).

3.5 Projected changes to ecosystems and stocks supporting freshwater fisheries

Freshwater fisheries play an important role in the food security of inland communities in Melanesia. For example, communities living along parts of the Fly River in PNG consume up to 2 kg of fish per person per week (Swales, 1998). Although knowledge about freshwater fisheries production remains poor, most of the production comes from PNG. Significant harvests are also made in Fiji and Solomon Islands. Total catches of fish and invertebrates from freshwater habitats in the tropical Pacific are estimated to total approximately 24 000 tonnes per year and contribute 4 percent of the regional contributions to GDP derived from fisheries (Gillett, 2009). The extent of some of the freshwater fish habitats that support freshwater fisheries is significant – the Sepik-Ramu, Fly and Purari rivers in PNG have annual discharges among the highest in the world (Gehrke *et al*., 2011a).

This section summarizes the vulnerability of the broad range of freshwater fish habitats that occur along the highland-to-coastal floodplain gradients in the western Pacific, and the stocks of fish and invertebrates supported by these habitats, to climate change. The main focus is on the effects of the projected changes in air temperature, rainfall, cyclones and sea-level rise on freshwater fish habitats, and the direct and indirect effects of climate change on fish and invertebrates, projected to occur by 2035, 2050 and 2100. Further details of these projected effects are provided in Gehrke *et al*. (2011a,b).

Projected effects on freshwater habitats

Freshwater habitats are expected to be exposed to increases in air temperature and, therefore, higher evaporation and water temperatures. Shallow, low-flow environments, such as high-elevation lakes, river edges and floodplain wetlands, will be sensitive to these changes. For example, the limited mixing in shallow freshwater floodplain habitats is likely to result in water temperatures that exceed the tolerance of many fish and invertebrates. There is also concern that the macrophyte species that create fish habitats may have limited capacity to adapt to increasing water temperatures.

Freshwater habitats are expected to be highly exposed and sensitive to changes in rainfall. Higher rainfall will lead to greater flows and flooding, which will improve connectivity between the mosaic of freshwater fish habitats in lowland areas but also increase erosion and sedimentation. On balance, freshwater habitats in the tropics are expected to benefit from the projected increases in rainfall. The vegetation that helps create many fish habitats is also likely to have much potential to adapt to increases in the frequency and duration of inundation. In the subtropics, decreases in rainfall are expected to reduce flows and connectivity.

Within the cyclone belt, freshwater habitats in coastal areas may be exposed to more severe flooding and the vegetation that creates many freshwater habitats will be sensitive to damage by floods associated with cyclones. Floods can also change riverine landscapes. Potential impacts include creation of new channels, transport of coarse sediments, floodplain sedimentation, the collapse of river banks and scouring of river beds. However, freshwater river habitats are dynamic systems that change and reform in response to floods, provided the capacity for river beds to expand and contract is not constrained.

Freshwater habitats in low-lying coastal areas will also be exposed to inundation by sea water due to projected sea-level rise, and during storm surge associated with cyclones. The plants in these habitats will be sensitive to the changes in salinity and have limited capacity to adapt to extended inundation by salt water.

Provided catchments are well managed, freshwater habitats in tropical Melanesia have the potential to benefit from the increasing rainfall that will enhance river flows and result in better growth of aquatic vegetation at higher temperatures. Increases in the area of freshwater fish habitat up of 10 percent by 2035, 20 percent by 2050 and >20 percent by 2100 are projected to occur in the tropics. Comparable decreases in habitat are expected in the subtropics.

Vulnerability of freshwater fisheries to the direct effects of climate change

Freshwater fish and invertebrates are expected to be exposed to temperature increases of 0.5–1.0°C by 2035, 1.5°C by 2050 and up to 3.0°C by 2100. Clearing of catchment vegetation may also increase the warming of aquatic habitats. Species inhabiting shallow low-flow environments, such as high-elevation lakes, river edges and floodplain wetlands, are expected to have the greatest sensitivity to warmer temperatures. Increasing water temperatures are likely to have potential impacts on larval fish growth, muscle fibre development, swimming ability, metabolic rate and sex ratios. The distributions of fish and invertebrate species currently limited by the lower temperature tolerances of species are expected to expand as waters warm. Growth rates should also increase where temperatures remain within the ranges tolerated by species. However, where increases in temperature are coupled with contaminants from mining, forestry and intensive agriculture operations, the temperature tolerances of species are likely to decrease.

As water temperatures increase, freshwater fish and invertebrates will be exposed to decreases in O_2. Greater oxygen demand at higher temperatures will make freshwater fish and invertebrate species particularly sensitive to reductions in O_2, although sensitivity of species is expected to vary, depending on their preferred habitats and tolerance to O_2 depletion. Potential impacts include limits to recruitment and increases in invasive fish species that tolerate low O_2 levels. Adaptations by fish and invertebrates to low O_2 levels include avoidance of hypoxic habitats or the ability to respire from the air-water interface. In locations with low flow where increased temperature (and perhaps salinity, see below) reduce O_2 significantly, fish assemblages are likely to be dominated by hypoxia-tolerant species.

Projected changes in rainfall will also expose freshwater fisheries resources to increases in river flow in the tropics and decreases in the subtropics. Freshwater fish and invertebrates are likely to respond positively to the increases in water quality and habitat area resulting from greater flows through effects on habitat availability, nutrient transport, food web processes and cues for migration. Negative responses are expected where rainfall and flow are reduced.

Exposure of freshwater fish and invertebrates to increased turbidity under future climatic conditions will depend on the state of catchment vegetation. Rivers draining catchments where vegetation is intact are likely to experience only minor increases in turbidity due to limited transport of sediments in runoff. However, in catchments that have been extensively cleared, the projected increases in rainfall are expected to cause some naturally clear streams to become permanently turbid. Heavy suspended sediment loads can damage the gill epithelium of fish and affect respiration. Increased deposition of sediments reduces the reproductive success of species with adhesive eggs. Potential impacts include reduced recruitment success by some fish species and reduced growth and survival of fish with a high dependence on visual feeding. The capacity of freshwater fish to adapt to increased turbidity will depend on the species and the prevailing environmental conditions – species inhabiting naturally turbid rivers will be less sensitive than those in habitats with clear water.

The fish and invertebrate species inhabiting lowland rivers will be exposed to projected sea-level rise and associated increases in salinity, especially during drought years when salt water penetrates further inland. The sensitivity and adaptive capacity of these species will depend on their salinity tolerances. Changes in species composition can be expected to occur, with estuarine species expected to replace freshwater fish and invertebrates in existing lowland reaches.

Vulnerability of freshwater fisheries to the indirect effects of climate change
Freshwater fish and invertebrates will also be exposed to climate change through the expected alterations to their habitats described above. These species are likely to be highly sensitive to such changes because they depend on a range of habitats within rivers, lakes, floodplains and estuaries for shelter and food. The potential effects include: 1) lower catches of coldwater species in the highlands of PNG as the extent of their habitat is reduced due to higher air temperatures; and 2) increased yields of fish from lowland river areas as the extent of floodplain habitat expands due to higher rainfall. The capacity of fish and invertebrates to take advantage of increased floodplain habitat will depend on removing any barriers to movement into the additional habitat. It will also depend on maintaining catchment vegetation in good condition to prevent erosion and pollution.

Future freshwater fisheries catches
Freshwater fish and invertebrates are expected to have a low overall vulnerability to the direct and indirect effects of climate change, except in disturbed catchments. Indeed, the overall effects of climate change on these species are expected to be positive. Ultimately, the projected changes in freshwater fisheries production are estimated to translate into increased catches of 2.5 percent by 2035, up to 7.5 percent by 2050 and up to 12.5 percent by 2100 where catchments are well managed. However, catches are likely to be reduced in catchments where poorly planned mining, forestry and agriculture have degraded aquatic habitats and the surrounding vegetation, thereby increasing the vulnerability of fisheries species to climate change.

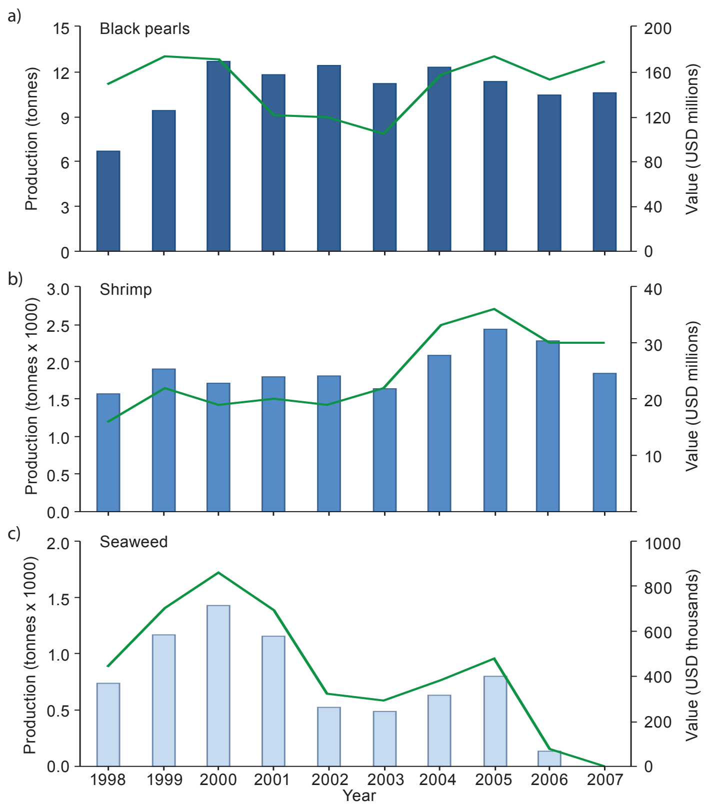
3.6 Projected effects on aquaculture

Aquaculture has considerable potential to contribute to food security and sustainable livelihoods in the tropical Pacific. A wide range of aquaculture activities are currently underway in 16 PICTs. In general, freshwater aquaculture activities focus on producing commodities for food security, whereas mariculture activities in coastal waters are usually aimed at creating livelihoods. Small pond aquaculture is now beginning to expand in inland PNG, where >10 000 households are engaged in growing Nile tilapia (Pickering *et al*., 2011). Cultured pearls from the black-lipped pearl oyster *Pinctada margaritifera* in French Polynesia, Cook Islands and Fiji (worth >USD 150 million per year), shrimp *Litopenaeus stylirostris* farmed in New Caledonia (worth about USD 30 million per year) and seaweed *Kappaphycus alvarezi* grown in Fiji, Kiribati, PNG and Solomon Islands, are the main aquaculture commodities produced for livelihoods (Figure 9) (Ponia, 2010). However, a range of other species are also produced (Table 13).

The species used to produce aquaculture commodities are potentially vulnerable to the changes in surface climate, the ocean and coastal habitats described in Sections 3.1, 3.2 and 3.4 above. This section summarizes the vulnerability of the range of aquaculture activities in the region to climate change based on the exposure and sensitivity of the

FIGURE 9

Production of (a) all black pearl products in French Polynesia, (b) shrimp in New Caledonia, and (c) seaweed in Kiribati between 1998 and 2008; the green line represents the value of production



Source: Ponia 2010.

species and infrastructure used to produce each commodity to the changes in air temperature, rainfall, cyclones and sea-level rise projected to occur by 2035, 2050 and 2100. Further details of the projected effects of climate change on aquaculture are provided in Pickering *et al.* (2011).

Commodities for food security

Tilapia and carp

Aquaculture operations for tilapia and carp are expected to be exposed to projected increases in water temperature and rainfall. Low-lying ponds near the coast are also expected to be exposed to sea-level rise and possibly more intense cyclones. Tilapia and carp farming will be sensitive to these changes because temperature regulates growth and reproduction of these fish, and rainfall influences water temperature and water exchange (and its effect on dissolved O_2 levels) in ponds. Aquaculture operations for tilapia and carp are expected to benefit from the projected increases in temperature and rainfall as growth rates increase and the more locations become suitable for pond aquaculture. Nevertheless, care will be needed to build ponds where they are not prone to flooding or to inundation or damage from sea-level rise or storm surge. The relative ease with which stocking densities can be altered to suit prevailing conditions and feed availability should enable tilapia and carp farming operations to adapt to climate change. Intensive culture systems that rely on high stocking densities are expected to have a lower adaptive capacity than extensive farming operations.

Milkfish

Farming milkfish in ponds is expected to have a similar vulnerability to operations growing tilapia, i.e. milkfish will be exposed to increases in water temperature and

TABLE 13

The aquaculture commodities produced for food and livelihoods in Pacific Island countries and territories (PICTs), together with the culture systems used to produce them, the environments where they are grown, and the PICTs in which each aquaculture activity is established or under investigation

Commodity	Culture system(s)	Environment(s)	PICTs involved*
Food security			
Tilapia	Earthen ponds	Terrestrial	American Samoa, Cook Islands, Fiji, Guam, Kiribati, CNMI, PNG, Samoa, Solomon Islands, Tuvalu, Vanuatu
Carp	Earthen ponds, river releases	Terrestrial	Fiji, PNG
Milkfish	Earthen ponds, stone-walled sea pens	Terrestrial, shallow lagoons	Cook Islands, Fiji, Guam, Kiribati, Nauru, Palau
Livelihoods			
Pearls	Submerged or surface longlines	Deep lagoons, sheltered bays	Cook Islands, Fiji, French Polynesia, FSM, Kiribati, Marshall Islands, PNG, Solomon Islands, Tonga
Shrimp	Earthen ponds, cement tanks	Terrestrial, adjacent to brackish or marine water source	French Polynesia, Fiji, Guam, New Caledonia, CNMI, PNG, Vanuatu
Seaweed	Off-bottom longlines, floating longlines	Shallow sandy back-reef areas of lagoons	Fiji, Kiribati, PNG, Solomon Islands
Marine ornamentals**	Seabed racks, floating cages	Lagoons	Cook Islands, Fiji, French Polynesia, FSM, Kiribati, Marshall Islands, Palau, Solomon Islands, Tonga, Vanuatu
Freshwater prawns	Earthen ponds	Terrestrial	Cook Islands, Fiji, Vanuatu
Marine fish	Floating sea cages, land-based raceways	Lagoons, sheltered bays	French Polynesia, New Caledonia, Palau, Marshall Islands, CNMI, PNG, Vanuatu
Sea cucumber	Released in the wild, pen grow-out, pond grow-out	Seagrass beds	Fiji, FSM, Kiribati, New Caledonia, Palau, Solomon Islands
Trochus	Land-based tanks, released in the wild	Coral reefs	Kiribati, Marshall Islands, Palau, Solomon Islands, Tonga, Vanuatu

Source: Pickering *et al.* 2011.

* Includes past activities; ** includes giant clams propagated in hatcheries, fragments of wild corals and 'live rock', and collection of wild postlarvae.

rainfall, and low-lying ponds near the coast could also be exposed to sea-level rise and possibly more intense cyclones.

Ocean acidification and changes in coastal habitats (Sections 3.2 and 3.4) could also affect the supply of wild-caught fry used to produce this commodity. Milkfish are likely to be sensitive to increases in temperature because it regulates growth, and to changes in rainfall which modulate water temperature and water exchange in ponds. Milkfish are expected to grow faster at warmer water temperatures, and increases in SST should extend the geographical range and season for capturing wild juveniles. The number of areas where ponds can be constructed should also increase with higher rainfall. If climate change increases variation in the supply of wild fry, larger-scale milkfish farming enterprises could adapt by producing juveniles in hatcheries. Because milkfish can be grown in both fresh water and under estuarine conditions, low-lying ponds near the coast vulnerable to sea-level rise and storm surge can be relocated further inland.

Commodities for livelihoods

Pearls

Pearl farming based on black-lipped pearl oysters will be exposed to increases in SST, ocean acidification, decreases in salinity due to changing rainfall patterns, sea-level rise and possibly more intense cyclones. The pearl oysters are sensitive to increases in SST because they become more susceptible to disease and parasites. SST also affects nacre deposition and pearl quality. Reduced salinity and increased sedimentation stemming from high rainfall can cause mass mortality of the oysters. Survival and growth of the spat used to produce adult oysters for 'seeding', calcification of shells and pearl quality are all expected to be affected negatively by ocean acidification. The effects of sea-level rise and more intense cyclones also increase the exposure of pearl farm infrastructure to damage. Adaptation options include increasing the proportion of spat produced in hatcheries; growing oysters in deeper (cooler) water; harvesting pearls during the cooler season, and culturing pearl oysters at sites with lower CO_2 concentrations.

Shrimp

Farming operations will be exposed to the effects of increases in temperature, changes in rainfall and ocean acidification on shrimp species, and the effects of sea-level rise and possibly stronger storm surge from more severe cyclones on shrimp pond infrastructure. *Litopenaeus stylitrostris* grown in New Caledonia is expected to be sensitive to increasing or more variable water temperature and rainfall. In the shorter term, shrimp farming may benefit from higher growth rates and improved yields due to increasing temperature. However, potential longer-term negative impacts include greater risk of temperature-related diseases and problems in drying out ponds between production cycles as sea level rises. Shrimp farming enterprises can adapt to the effects of sea-level rise by adding soil to the floor of ponds and increasing the height of the walls so that ponds continue to drain efficiently. Ultimately, new ponds may need to be constructed at higher elevations, and shrimp may need to be farmed more intensively. In addition, the warming conditions may enable the shrimp farming industry to grow a wider variety of species in more tropical areas.

Seaweed

Seaweed *Kappaphycus alvarezii* is expected to be exposed to increases in SST, rainfall and dissolved CO_2 and changed patterns of water movement due to sea-level rise. Some seaweed farming operations are likely to be exposed to more intense cyclones. *Kappaphycus* is sensitive to increased SST and reduced salinity, which stress the plants and retard growth, resulting in crop losses due to increased incidence of outbreaks of epiphytic filamentous algae and tissue necrosis. Lower salinities caused by increased rainfall are likely to reduce the number of sites where seaweed can be grown. Higher levels of dissolved CO_2 and sea-level rise may benefit seaweed farming by stimulating growth and promoting water exchange. More intense cyclones would increase the risk of damage to the equipment used to grow seaweed in Fiji, but not in Kiribati, PNG and Solomon Islands which are not in the cyclone belt. There is limited scope for adaptation of seaweed farming at the regional level by shifting production to higher latitudes.

Marine ornamentals (giant clams and corals)

Marine ornamental aquaculture is expected to be exposed to projected increases in SST, changes in rainfall, ocean acidification, sea-level rise, degradation of habitats and possibly more intense cyclones. Corals and giant clams are sensitive to increased SST, which affects their growth and survival due to more regular bleaching. They are also sensitive to changes in salinity and turbidity caused by higher rainfall, and reduced aragonite saturation levels from ocean acidification (Section 3.2). Accordingly, conditions for producing the main marine ornamental products are likely to deteriorate. In some locations, sea-level rise could reduce the potential impact by improving water exchange and nutrient supply to nutrient-poor sites. Transferring operations from the sea to tanks on land with controlled water temperature and pH, and developing markets for species of coral that are more tolerant to the changing marine environment, should assist enterprises producing ornamental species to adapt to climate change.

Freshwater prawns
The culture of freshwater prawns *Macrobachium* spp. is expected to be exposed to increases in water temperatures and rainfall, and the possible effects of more intense cyclones. Freshwater prawns are sensitive to increases in water temperature and should grow more rapidly provided temperatures remain within thermal limits. Higher rainfall should increase opportunities to farm freshwater prawns. The expected expansion of freshwater habitats (Section 3.5) should also increase the supply wild juvenile *Macrobrachium lar* for grow-out operations. To adapt to the possible adverse effects of extreme water temperatures, ponds for growing freshwater prawns should be built in locations where high water turnover rates can be achieved.

Marine fish
Species of marine fish produced in hatcheries and grown in sea cages will be exposed to increases in SST, and farm infrastructure could be at greater risk from the possibility of more severe cyclones. The sensitivity of hatchery-based marine fish aquaculture to higher SST is expected to be low because these operations rely on controlled facilities to maintain broodstock and rear juveniles. However, operations relying on collection of wild juveniles for grow-out may be sensitive to the effects of SST on the spawning cycle of adult fish. Sensitivity of marine fish grown-out in sea cages to increases in SST should be similar to the responses of demersal fish associated with coastal habitats (Section 3.4), i.e. growth could be inhibited under the A2 emissions scenario by 2100. The potential impact of climate change on prospective marine fish species, or the infrastructure needed to produce them, is estimated to be low. The industry has yet to develop in the region and the possible effects can be taken into account when assessing the suitability of present and future environmental conditions for hatcheries and sea cages.

Sea cucumbers
Farming and/or sea ranching of sea cucumbers are expected to be exposed and sensitive to increases in air temperature, SST, rainfall, ocean acidification, sea-level rise and possibly cyclone intensity. These operations will also be exposed to changes in seagrass habitat (Section 3.4). Higher temperatures, reduced salinity and ocean acidification, and degraded seagrass habitats are likely to increase the mortality of hatchery-reared juveniles released in the wild. In subtropical areas, farming in ponds should benefit from the faster growth rates of sea cucumbers in warmer water. However, in the tropics, sea cucumbers grown in ponds may suffer higher mortality due to the increased likelihood of stratification caused by higher rainfall. Where such problems occur, ponds for growing sea cucumbers will need to be modified to maximize mixing.

Trochus
Restocking programmes for trochus are expected to be exposed to increases in SST, lower salinity, ocean acidification, sea-level rise and possibly increases in cyclone intensity. They will also be sensitive to these changes. The salinity of intertidal pool nursery habitats for trochus is expected to fall below their tolerance in some locations. Sea-level rise is also likely to reduce the availability of this habitat where steep terrain blocks intertidal areas migrating landward. Greater storm surge from more intense

cyclones is likely to cause higher mortality of trochus released on reefs. The effect of ocean acidification on trochus shells remains to be determined. The main adaptation for restocking programmes will be to focus on translocation of adult trochus to form breeding populations. Where it proves necessary to use hatchery-reared animals, cultured trochus should be released at the largest size possible to reduce the need to use intertidal areas as release sites.

Overall vulnerability of aquaculture production

The combined effects of climate change on species and infrastructure indicate that 1) existing and planned aquaculture activities to produce tilapia, carp and milkfish in freshwater ponds for food security are likely to benefit; and 2) mariculture enterprises producing commodities for livelihoods in coastal waters are likely to encounter production problems. The benefits for freshwater aquaculture are expected to be apparent by 2035 (Table 14), provided that the changing climate does not limit access to the fishmeal needed to formulate appropriate diets for tilapia, carp and milkfish.

Although some of the commodities produced for livelihoods in coastal waters are likely to benefit from changes in specific environmental variables, when the effects of all changes to the environment are combined most commodities are expected to begin to become vulnerable by 2035 (Table 14). Shrimp and seaweed are exceptions. Increases in water temperatures may well improve shrimp yields by 2035. On the other hand, increases in SST and rainfall by 2035 are likely to make seaweed farming moderately vulnerable to crop losses due to increased incidence of epiphytic filamentous algae and tissue necrosis.

By 2100, the effects of climate change and ocean acidification on all livelihood commodities are expected to be negative (Table 14). Seaweed farming and production of marine ornamentals are likely to have a high vulnerability, and the culture of pearls is expected to be moderately vulnerable. Shrimp farming, marine fish culture, sea

TABLE 14

Vulnerability of aquaculture commodities to projected climate change 2035, 2050 and 2100. The likelihood and confidence values associated with these projections are also shown

Commodity	Vulnerability		
	2035	2050	2100
Food security			
Tilapia and carp	L (+)	L-M (+)	M (+)
Milkfish	L (+)	L (+)	L (+)
Livelihoods			
Pearls	L (-)	L (-)	M (-)
Seaweed	M (-)	M-H (-)	H (-)
Shrimp	L (+)	L (-)	L–M (-)
Marine ornamentals	L (-)	M (-)	H (-)
Freshwater prawn	L (+)	L (-)	L (-)
Marine fish	L (-)	L (-)	L-M (-)
Sea cucumbers	L (-)	L (-)	L-M (-)
Trochus	L (-)	L (-)	L (-)

Source: Pickering *et al.* 2011.

Unlikely | Somewhat likely | Likely | Very likely
0% | 29% | 66% | 90% | 100%
Likelihood

Very low | Low | Medium | High | Very high
0% | 5% | 33% | 66% | 95% | 100%
Confidence

TABLE 15

Projected changes in efficiency of aquaculture in 2035, 2050 and 2100, relative to 2010 The likelihood and confidence values associated with these projections are also shown

Commodity	Production efficiency		
	2035	2050	2100
Food security			
Tilapia and carp	↑	↑	↑
Milkfish	↑	↑	↑
Livelihoods			
Pearls	↓	↓	↓
Seaweed	↓	↓	↓
Shrimp	↑	↓	↓
Marine ornamentals[a]	↓	↓	↓
Freshwater prawn	↑	↓	↓
Marine fish	↓	↓	↓
Sea cucumbers	↓	↓	↓
Trochus	↓	↓	↓

Source: Pickering *et al.* 2011.

Low Medium High

Projected increase

Low Medium High

Projected decrease

ranching/pond farming of sea cucumbers and restocking programmes for trochus are all expected to have a low to moderate vulnerability.

Future aquaculture production

Plans to increase the production of tilapia, carp and milkfish in ponds are expected to be favoured by climate change (Table 15). Although most mariculture commodities are expected to become progressively more vulnerable to climate change, this does not necessarily mean that there will be reductions in productivity in the future. Rather, the efficiency of enterprises is likely to be affected (Table 15). Total production of coastal aquaculture commodities could still increase if aquaculture operations remain viable and more enterprises are launched.

3.7 Vulnerability of economies and communities

The substantial economic and social benefits derived from fisheries and aquaculture by PICTs, and the plans to sustain and expand those benefits (Section 2.7), are expected to be affected by the projected changes in productivity of oceanic, coastal and freshwater fisheries, and aquaculture, described in Sections 3.3 to 3.6. The effects on national economies of changes in the contributions of industrial tuna fisheries to GDP and government revenue, and the vulnerability of food security in PICTs to changes in coastal fisheries production, have been assessed by Bell *et al.* (2011c). The main findings are summarized below.

Potential effects on GDP and government revenue

The projected increases in catches of skipjack tuna by 2035 from preliminary modelling (Section 3.3) show that landings are expected to rise by about 20 percent across the fishery, driven by strong increases (30–35 percent) in catch in the eastern part of the region relative to 1980–2000 and more modest increases (10 percent) in catches in the west (Table 8). The expected improvements in catch lead to projected increases in GDP and government revenue by 2035, particularly for those PICTs in the east (Table 16).

The most significant projected increases to GDP are expected to occur in American Samoa (3–6 percent) and Marshall Islands (2–6 percent), whereas the greatest increases in government revenue are likely in Kiribati (11–18 percent), Tuvalu (4–9 percent), Tokelau (1–9 percent) and Nauru (2–6 percent) (Table 16).

By 2050, the catch of skipjack tuna in the eastern region of the fishery is projected to increase by >40 percent relative to 1980–2000, with no change in the western region (Table 8). For PICTs in Micronesia and Polynesia, the general level of benefits projected for 2035 are expected to continue in 2050 (Table 16). On the other hand, the projected decreases in catch of 11 percent in PNG and 5 percent in Solomon Islands by 2050 (Lehodey *et al*., 2011) are expected to lead to declines in GDP and government revenue. However, due to the relatively low importance of the surface fishery to the larger economies of these PICTs, GDP is estimated to decline by only 0.1–0.4 percent in both countries (Table 16). Government revenues from DWFNs are also expected to fall by only 0.1 percent in PNG and 0.3 percent in Solomon Islands.

By 2100, catches of skipjack tuna are projected to fall for the fishery as a whole by around 7 percent because the more modest projected increases in the east of the region relative to 1980–2000 of 25–30 percent are more than offset by the expected decline of 20 percent in the larger component of the fishery in the west (Table 8). The projected 30 percent decline in catches of skipjack tuna in the EEZ of PNG by 2100 (Lehodey *et al*., 2011) is particularly significant, although it is estimated to result in a reduction of only up to 1.2 percent in GDP, and 0.2 percent in government revenue, due to the large size of the economy in PNG. The projected declines in catches of skipjack tuna from Solomon Islands and FSM of about 15 percent (Lehodey *et al*., 2011) are also expected to cause reductions of about 0.8–1 percent in GDP, and about 1–2 percent in government revenue in both countries (Table 16). The catch in Nauru, and consequently government revenue, is expected to fall only marginally. Marshall

TABLE 16

Estimated changes in percentage contributions of industrial tuna fisheries to GDP and government revenues in Pacific Island countries and territories (PICTs), resulting from projected alterations in the catch of skipjack tuna in 2035, 2050 and 2100, relative to 1999–2008. Lower (L) and upper (U) limits for these projections are estimated for the period 1998–2008 and future times. Only PICTs where industrial fishing or processing contributes >1% of GDP or government revenue are included

PICT	Change to GDP (%)								Change to government revenue (%)							
	1999–2008 (%)		2035		2050		2100		1999–2008 (%)		2035		2050		2100	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
Melanesia																
PNG	1.5	4	0	+0.1	-0.2	-0.4	-0.4	-1.2	0.2	0.8	0	0	0	-0.1	-0.1	-0.2
Solomon Islands	2	5	+0.1	+0.2	-0.1	-0.3	-0.3	-0.8	0.2	5	0	+0.2	0	-0.3	0	-0.8
Micronesia																
FSM	1.5	5	0	+1	0	0	0	-1	6	12	+1	+2	0	+1	-1	-2
Kiribati									30	50	+11	+18	+13	+21	+7	+12
Marshall Islands	10	25	+2	+6	+2	+6	+1	+2	2	5	0	+1	0	+1	0	0
Nauru									10	25	+2	+6	+2	+5	0	0
Palau									2.5	3.2	+0.2	+0.3	0	+0.1	-0.7	-0.9
Polynesia																
American Samoa	20	25	+3	+6	+2	+4	-1	-2	5	20	+1	+4	+1	+2	0	-1
Tokelau									2	15	+1	+9	+1	+10	+1	+9
Tuvalu									10	25	+4	+9	+4	+10	+2	+6

Source: Bell *et al.* 2011c.

Islands, Kiribati and Tuvalu are projected to continue to receive increased economic benefits in 2100, albeit at lower levels than in 2035, or 2050 (Table 16).

Vulnerability of food security

Based on median estimated production of reef-associated fish of 3 tonnes per km^2 per year (Newton *et al*., 2007; Pratchett *et al*., 2011), and current freshwater fish production (Gillett, 2009; Gehrke *et al*., 2011b), several PICTs are already facing a large gap in the fish needed for good nutrition of their populations (Table 17). Continued rapid population growth in PNG, Solomon Islands and Vanuatu causes the projected availability of fish per person to decline substantially in 2035, 2050 and 2100 (Table 17). The changes in Solomon Islands are particularly dramatic – the estimated fish surplus of 15 kg per person per year in 2010 changes to a shortfall of 7 kg in 2035, 13 kg in 2050 and 21 kg in 2100. The gap also continues to widen for all these PICTs over time, although it does not increase substantially for Guam, Nauru and CNMI because the shortfalls in fish required for good nutrition based on coastal fisheries production are already very large (Table 17).

Climate change is expected to have relatively minor additional effects on availability of fish per person for these PICTs. When the projected effects of climate change in 2035, 2050 and 2100 on the abundances of coastal and freshwater fish (Sections 3.4 and 3.5) are added to the effects of population growth, the access to fish per person decreases by only 1–2 kg for all future periods for most of these PICTs (Table 18).

There are two reasons for this: 1) a very large gap already exists between the amount of fish needed for good nutrition and the estimated sustainable harvests from the areas of coral reefs in many of these PICTs; and 2) the effects of population growth alone on availability of reef-associated fish per person are profound (Table 17). Taken together, these factors leave little scope for climate change to increase the gap further. The exceptions are Fiji, Solomon Islands and Samoa, where the additional gap in the fish required due to climate change is expected to be relatively small initially but becomes more noticeable in 2050 and 2100 (Table 18).

TABLE 17

Gap between the recommended fish consumption of 35 kg per person per year, and the estimated annual supply of fish per person from coastal (reef-associated) and freshwater fisheries in 2010, and the increasing gap projected to occur in 2035, 2050 and 2100 due to population growth alone for selected Pacific Island countries and territories (PICTs). Note that the gap in PNG applies only to coastal communities and those living close to freshwater habitats – the gap is far greater for the very large inland populations which have little access to fish

PICT	Total fish available per person per year (kg)				Gap in fish needed for good nutrition per person per year (kg)			
	2010	2035	2050	2100	2010	2035	2050	2100
Melanesia								
Fiji	40	35	32	26	+(5)	0	3	9
PNG	12	8	6	4	23	27	29	31
Solomon Islands	50	28	23	14	+(15)	7	12	21
Vanuatu	16	10	8	6	19	25	27	29
Micronesia								
Guam	4	3	3	2	31	32	32	33
Nauru	2	1	1	1	33	34	34	34
CNMI	12	10	9	9	23	25	26	26
Polynesia								
American Samoa	17	13	11	8	18	22	24	27
Samoa	33	30	29	25	2	5	6	10

Source: Bell *et al.* 2011c.

+ Indicates that there is no gap (surplus fish).

TABLE 18

Gap between the recommended fish consumption of 35 kg per person per year, and the estimated annual supply of fish per person, from coastal (and freshwater) fisheries in 2035, 2050 and 2100 for selected Pacific Island countries and territories (PICTs) due to the effects of population growth (P) and the combined effects of population growth and climate change (CC)

PICT	Reef area (km²)[a]	Total fish production[b]	Population (x 1000)[c]			Total fish available per person per year (kg)			Gap in fish needed for good nutrition per person per year (kg)					
			2035	2050	2100	2035	2050	2100	2035		2050		2100	
									P	CC	P	CC	P	CC
American Samoa	368	1 104	87	98	135	13	11	8	22	23	24	26	27	29
Fiji	10 000[d]	34 146	978	1 061	1 332	35	32	26	0	1	3	7	9	15
Guam	238	717	250	268	296	3	3	2	32	32	32	33	33	33
PNG	22 000[d]	83 500	10 822	13 271	21 125	8	6	4	27	27	29	29	31	32
Nauru	7	21	14	16	21	1	1	1	34	34	34	34	34	34
CNMI	250	750	76	80	87	10	9	9	25	25	26	27	26	29
Samoa[e]	2 000	6 100	202	210	240	30	29	25	5	6	6	11	10	16
Solomon Islands	8 535	27 605	970	1 181	1 969	28	23	14	7	7	12	15	21	24
Vanuatu	1 244	3 812	400	483	695	10	8	6	25	25	27	28	29	30

Source: Bell *et al.* 2011c.

a = Derived from Hoegh-Guldberg *et al.* (2011); b = estimates assume sustainable fisheries production of 3 tonnes per km² of coral reef per year but also include freshwater fisheries production where relevant based on estimates by Gillett (2009); c = provided by SPC Statistics for Development Programme; d = preliminary estimates of coral reef habitat only; e = based on total reef area to a depth of 100 m; PNG = Papua New Guinea; CNMI = Commonwealth of the Northern Mariana Islands.

Relative vulnerability of PICTs

The relative vulnerability of the nine PICTs facing shortfalls in coastal fish production per person has been estimated using the framework in Figure 3 (see Bell *et al*., 2011c for details of the analyses).

In 2035, Fiji is expected to have a very low vulnerability (Table 19) to shortages of fish because estimated harvests are largely projected to provide 35 kg of fish per person per year for the increased population. Solomon Islands has a low vulnerability because the shortfall of 7 kg of reef-associated and freshwater fish per person per year projected to occur there is much lower than for most other PICTs except Samoa, which has a moderate vulnerability due to its traditionally high fish consumption

TABLE 19

Relative vulnerability scores of selected Pacific Island countries and territories (PICTs) to the availability of coastal (reef-associated) and freshwater fish for food security in 2035, 2050 and 2100. Scores have been classified as very low (0.00–0.05), low (0.06–0.10), moderate (0.11–0.20), high (0.21–0.30) or very high (> 0.30)

PICT	Emissions scenarios		
	B1/A2 2035	A2 2050	A2 2100
Melanesia			
Fiji	Very low	Very Low	Very Low
PNG	Very High	Very High	Very High
Solomon Islands	Low	Moderate	Moderate
Vanuatu	Very High	Very High	High
Micronesia			
Guam	Moderate	Moderate	Low
Nauru	Very high	Very high	Very high
CNMI	High	High	High
Polynesia			
American Samoa	Very high	Very high	Very high
Samoa	Moderate	Moderate	High

Source: Bell *et al.* 2011c.

(Table 4). Guam also has a moderate vulnerability but for a different reason – the potential impact of the great shortages of reef-associated fish per person expected to occur there is reduced by substantial national adaptive capacity. The vulnerability of CNMI is estimated to have a high rather than very high for similar reasons. American Samoa, Nauru, PNG and Vanuatu have a very high vulnerability to shortages in the recommended, or traditional, levels of fish consumption because of the projected limitations to the amount of fish available per person and weak adaptive capacity (Table 19).

These general patterns of vulnerability are expected to be maintained among these PICTs in 2050 and 2100, except in Samoa, Guam, Vanuatu and Solomon Islands (Table 19). The vulnerability of Samoa increases from moderate in 2050 to high in 2100 due to substantial decreases in access to fish per person. A similar trend also occurs in American Samoa. The relatively rapid increases in vulnerability scores in Samoa and America Samoa, reduces the relative vulnerability of Guam, which decreases from moderate in 2050 to low in 2100, and Vanuatu, which declines from very high in 2050 to high in 2100. The relative vulnerability of Solomon Islands increases from low in 2035 to moderate to high in 2050 and 2100 (Table 19).

Vulnerability of livelihoods

Plans to increase the number of livelihoods that can be sustainably based on coastal fisheries and aquaculture in the region are likely to be improved or inhibited by climate change, depending on the resource involved. Opportunities to increase the number of livelihoods based on the capture of nearshore pelagic fish species by coastal fisheries are expected to increase due to the higher projected abundances of skipjack and yellowfin tuna under climate change in the east until the end of the century, and in the west until 2035 (Section 3.3) (Table 20). Freshwater pond aquaculture is also expected to be progressively enhanced by the projected increases in rainfall and water temperatures (Section 3.6) and more opportunities to earn income from freshwater fisheries in PNG could eventuate for the same reasons (Section 3.5) (Table 20).

On the other hand, the productivity of the demersal fish and invertebrate components of coastal fisheries are expected to decline progressively (Section 3.4) (Table 20), limiting opportunities to create more livelihoods that could be gained from improved management of coastal fish habitats and stocks. Although there is much

TABLE 20

Summary of the direction of existing plans (outlined arrows) to derive more livelihoods from fisheries and aquaculture resources in Pacific Island countries and territories, and the likely effects of climate change in 2035, 2050 and 2100 on the outcomes of these plans in terms of percentage increases or decreases

Period	Oceanic fisheries		Coastal fisheries			Freshwater fisheries	Aquaculture	
			Nearshore pelagic fish		Other resources			
	West	East	West	East			Ponds	Coastal
Present	⇧	⇧	⇧	⇧	⇩	⇧	⇧	⇧
2035	⬆ (teal)	⬆ (black)	No effect	⬆ (black)	⬇ (cream)	⬆ (pale blue)	⬆ (pale blue)	⬇ (cream)
2050	No effect	⬆ (black)	⬇ (yellow)	⬆ (black)	⬇ (light orange)	⬆ (pale blue)	⬆ (pale blue)	⬇ (light orange)
2100	⬇ (dark orange)	⬆ (blue)	⬇ (light orange)	⬆ (blue)	⬇ (dark orange)	⬆ (pale blue)	⬆ (teal)	⬇ (light orange)

Source: Bell *et al.* 2011c.

scope for expansion of jobs based on mariculture in the near term, the efficiency of enterprises is also projected to decline (Section 3.6) (Table 20).

Formal analysis of the relative vulnerability of plans to optimize the number of livelihoods supported by fisheries and aquaculture among PICTs is not practical due to the problems involved in 1) constructing composite indices for exposure and sensitivity across the various oceanic and coastal fisheries and aquaculture resources involved; and 2) weighting the various components of exposure and sensitivity indices due to insufficient data on the jobs based on each resource (Bell *et al*., 2011c). Instead, PICTs should be able to determine the general impact of climate change on plans to create livelihoods across the sector from the information in Table 20.

Plans to maximize the number of sustainable livelihoods derived from fisheries and aquaculture does not depend only on the projected future status of resources. Climate change can be expected to affect other aspects of people's lives, for example, through inundation of coastal land, destruction of coastal infrastructure, or impacts on non-fishing features of coastal livelihood systems, including agriculture. Furthermore, climate change is not the only large-scale driver of change in employment opportunities in fisheries and aquaculture. Other drivers include technological change (e.g. substitution of labour by technology), changing demographics (rural-urban migration, international labour migration), shifts in culture, educational attainment and lifestyle aspirations (Gillett and Cartwright, 2010; Hall, 2011; Allison *et al*., 2011).

3.8 Implications

Economic development and government revenue

The projected increases in skipjack tuna catch in the east and decreases in the west (Section 3.3) indicate that the potential benefits to economies could exceed the threats. The possible advantages are that the significant contributions that licence fees already make to government revenue in Kiribati, Tuvalu, Tokelau and Nauru (Table 2) could increase as catch rates improve in their EEZs. More modest benefits to government revenue are also expected for FSM and Marshall Islands until 2050. Gross domestic product in Marshall Islands is also projected to increase until 2100 as a result of greater catches by their industrial fleet, and canning operations in American Samoa also have potential to benefit from the more eastern distribution of skipjack tuna until 2050, provided they remain economically viable in the intervening period (Table 16). Fiji may also have better access to fish for processing in the future.

The potential disadvantages are that the progressive movement of skipjack tuna further to the east may eventually affect the contribution of fishing and processing operations to GDP, and licence fees to government revenue, for some PICTs in the western part of the region (FSM, Palau, PNG and Solomon Islands). In particular, the plans to expand industrial fishing and processing in PNG and Solomon Islands to domesticate more of the benefits from tuna resources could be affected. Overall, however, the effects of any decline in industrial fishing and processing due to climate change on the GDP of PNG and Solomon Islands would be limited because industrial fishing and processing make relatively small contributions to the national economies of these PICTs (Tables 2 and 16).

The potential opportunities for PICTs in the east arising from altered distributions of tuna due to climate change may be tempered, and the disadvantages for PICTs in the west reinforced, by: 1) the effects of increasing fuel prices on the costs of catching and transporting fish (Wilson and McCoy, 2009); 2) the costs involved in upgrading fleets operating or based in subtropical PICTs to provide acceptable standards of safety at sea (Gillett, 2008; FAO, 2009) during more severe storms (Section 3.1); and 3) the projected effects of sea-level rise (Section 3.2), which are eventually expected to result in some shore-based facilities having to be rebuilt or relocated, and 'climate proofing' of future infrastructure.

Food security

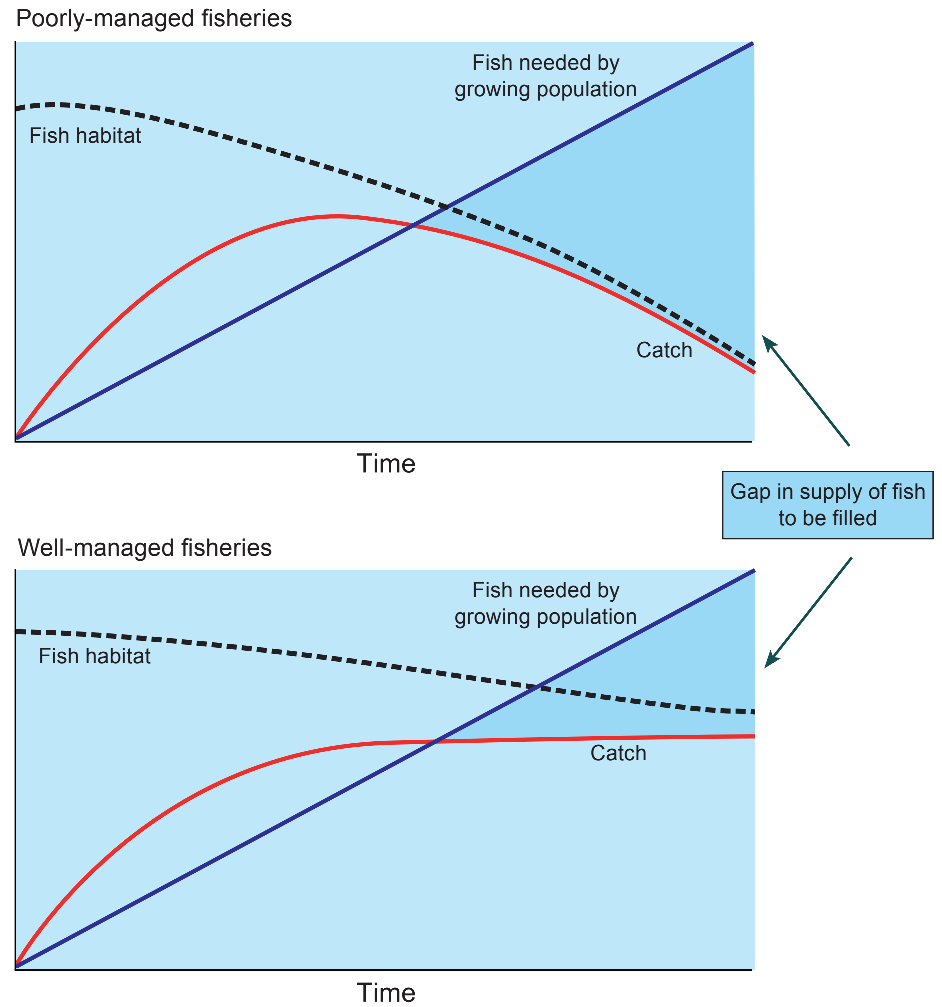
The expected shortfalls between the fish required for good nutrition and the catches of fish likely to be available from coastal and freshwater habitats has two profound implications for the PICTs listed in Table 18. These implications are summarized below.

Stocks of coastal and freshwater fish and invertebrates, and the habitats they depend on, will need to be managed as well as possible to reduce the gap between the amount of fish needed for good nutrition and the quantity of fish that can be harvested sustainably (Figure 10). This gap already exists in some PICTs (Table 17) and will increase progressively due to population growth and the projected direct and indirect effects of climate change on stocks (Table 18). Good management will improve opportunities for coastal and freshwater fish habitats and stocks to deliver their potential sustainable yields. It will also enable these natural resources to exercise their potential capacity to adapt to climate change (Sections 3.4 and 3.5).

The gap will need to be filled mainly with tuna, and to some extent with tilapia from pond aquaculture. Because a progressive decline is expected in the relative contribution of coastal fisheries to the fish required for food security due to the limits on production

FIGURE 10

The importance of managing coastal and freshwater fish habitats and stocks well to minimise the gap between the fish required by rapidly growing populations in several Pacific Island countries and territories for food security, and potential sustainable harvests of fish from coastal fisheries



Source: Bell *et al.* 2011c.

from coastal habitats, and the projected direct and indirect effects of climate change on stocks (Section 3.4), tuna will need to play an increasingly important role in meeting the shortfall of fish needed for food security. The role of tuna in providing fish for food security in the future is profound – not only does the amount of fish needed increase over time but tuna has to supply an increasing percentage of the total fish required (Bell *et al*., 2011c).

Papua New Guinea and Solomon Islands stand out from the other PICTs as countries where recent catches of tuna from their national EEZs (and archipelagic waters) can directly supply the additional fish required for food security (Table 4), although Nauru is also in this category. An important implication for PNG and Solomon Islands is that, due to the effects of population growth alone, an increasing proportion of annual average tuna catches will need to be allocated over time to provide the quantities of fish their populations need for good nutrition. These proportions reach 22 percent and 16 percent for PNG and Solomon Islands, respectively, in 2050, increasing to 43 percent and 38 percent in 2100. The projected effects of climate on the distribution and abundance of skipjack tuna indicate that these proportions would increase marginally in 2050, and to about 60 percent for PNG and about 45 percent for Solomon Islands by 2100 (Bell *et al*., 2011c). Although some of this allocation will need to be given directly to coastal communities to catch tuna in nearshore waters, it is expected to have little effect on the profitability of tuna canneries in PNG and Solomon Islands because 1) the processing facilities already market substantial proportions of their products on the domestic market; and 2) canned tuna is one of the most practical vehicles for making more fish available to rapidly growing populations.

Pond aquaculture, which is expected to be favoured by climate change (Section 3.6) has potential to make locally important contributions, possibly amounting to about 10 percent of the total fish required nationally by 2100, in some PICTs (Bell *et al*., 2011c).

Livelihoods

The implications of the projected changes in production of coastal and freshwater fisheries and aquaculture for plans to create additional sustainable livelihoods from these resources are that income-earning activities may need to be switched from one resource to another. Small-scale fishing effort will need to be increasingly transferred from demersal fish associated with coral reefs, mangroves and seagrasses to nearshore pelagic species, particularly skipjack and yellowfin tuna. Transferring effort to nearshore pelagic species is not only expected to maintain the livelihoods of fishers as the projected declines in coastal fisheries occur (Section 3.4), it should create additional job opportunities in several PICTs because of the likely beneficial effects of climate change on tuna stocks in the short term, and prolonged benefits for PICTs in the east in the long term (Table 8). For aquaculture, much of the potential for growth in jobs is expected to be based on farming freshwater fish in ponds (Section 3.6).

4. Adaptations and supporting policies

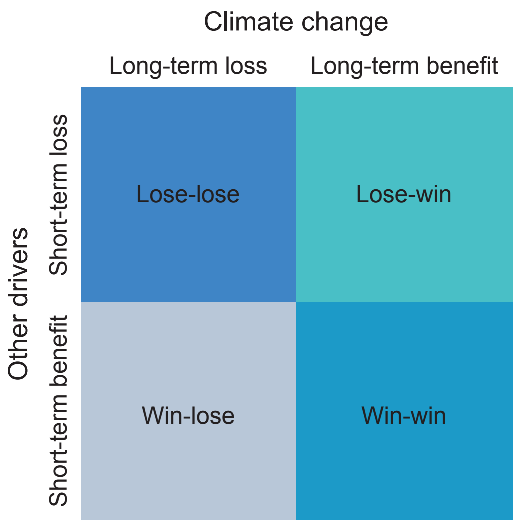
The projected effects of climate change on the production of oceanic, coastal and freshwater fisheries and aquaculture (Section 3) are not the only future 'drivers' of the sector. Population growth and urbanisation, patterns of economic development, status of fisheries resources in other oceans, governance 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 (Hunt, 2003; Gillett and Cartwright, 2010; Hall, 2011). Population growth and urbanisation are expected to be particularly significant, especially in Melanesia (Bell *et al*., 2011c).

Most of these factors have the potential to affect fisheries and aquaculture before the projected effects of climate change become limiting. Therefore, a framework is needed for planned adaptations that addresses the other drivers in the near term, and climate change in the longer term (Grafton, 2010). Clearly, the best investments are those that deliver short-term and long-term benefits ('win-win' adaptations) (Figure 11). But adapting to climate change will also involve some 'lose-win' adaptations. For such adaptations, the economic and social costs exceed the benefits in the near term, but investments position PICTs to receive net benefits under climate change.

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 supporting fisheries and aquaculture. There are potential social barriers to the uptake of appropriate technology (Adger *et al*., 2009; Moser and Ekstrom, 2010). Such barriers include the cultural norms and gender issues that can limit broad-based community participation. Therefore, 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.

FIGURE 11

Decision framework for identifying adaptations to address other drivers in the short term and climate change in the long term



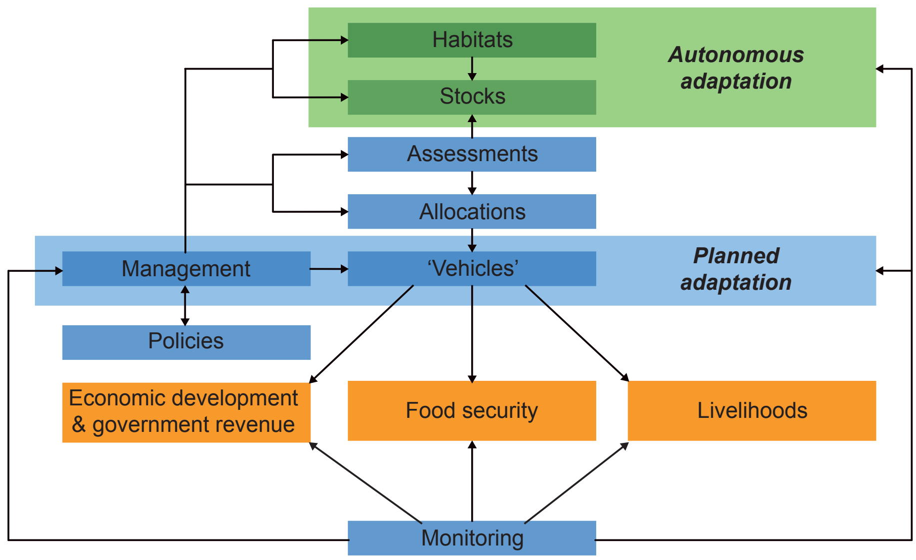
Source: Grafton 2010.

The main prospective win-win and lose-win adaptations and policies to reduce threats to the continued important contributions of fisheries and aquaculture to economic development, government revenue, food security and livelihoods, and capitalize on the opportunities, are outlined in this section. These adaptations and policies assume that 1) the key objectives of national agencies responsible for managing fisheries and aquaculture are to maximize the sustainable socio-economic benefits listed immediately above; 2) planned adaptations are needed to improve the way that fisheries and aquaculture activities deliver these benefits; and 3) the fish habitats and fish stocks that underpin these benefits are managed in ways that maximize their capacity for autonomous adaptation to the effects of climate change (Figure 12).

It is also assumed that adaptations will be designed and delivered in a way that is acceptable to those whom they are intended to benefit. This important prerequisite is expected to be relatively easy to achieve because the ways that Pacific people traditionally respond to and cope with extreme events such as cyclones and droughts (Ruddle and Johannes, 1990; Nunn, 2007; Reenberg *et al*., 2008; UNDP/AusAID, 2009; UNESCO/Monash University, 2011), should predispose them to embracing and implementing the recommended adaptations. Improvements can be made, however, to traditional ways of responding to extreme events. Such improvements include increasing the participation of women in all aspects of planning and applying adaptations, and ensuring that the people likely to be affected are involved in negotiations to select and implement adaptations, so that their rights are respected (Charles, 2011).

FIGURE 12

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



Source: Bell *et al.* 2011d.

4.1 Economic development and government revenue

The adaptations and supporting policies required to maximize the benefits from tuna fisheries for PICTs in the central and eastern Pacific, and to minimize the impacts for PICTs in the west, centre around 1) developing 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) optimizing the productivity of tuna resources across the region. The priority adaptations are described in detail by Bell *et al*. (2011d) and summarized below.

Full implementation of the vessel day scheme (win-win): The 'cap and trade' provisions of the vessel day scheme (VDS) enable all members of the parties to the Nauru Agreement to receive some level of benefits during ENSO events, regardless of where tuna are concentrated (Aqorau, 2009). As redistribution of tuna occurs, the periodic adjustment of allocated vessels days within the VDS will reduce the need for members in the east to purchase days from those in the west.

Develop and maintain an economic partnership agreement (EPA) with the European Union (win-win): The global sourcing provisions of an EPA assist countries processing tuna to obtain and export fish at competitive prices. Developing and maintaining an EPA will help ensure that these countries have continued supplies of fish as tuna are redistributed further east.

Diversify sources of fish for canneries (win-win): Other adaptations to help PICTs in the west secure fish for canneries include: reducing access for DWFNs to their EEZs to provide more fish for national vessels, requiring DWFNs to land some of their catch for use by local canneries, and enhancing arrangements for national fleets to fish in the EEZs of other PICTs.

Immediate conservation and management measures for tuna (win-win): Stopping the overfishing of bigeye tuna, and preventing overfishing of skipjack and yellowfin tuna and South Pacific albacore, will maintain stocks at healthy levels and make these valuable species more resilient to climate change.

Energy efficiency programmes for industrial fleets (win-win): Energy audits to identify how to reduce fuel use during fishing operations should assist fleets to cope with rises in oil prices. Energy audits should also reduce the costs for fleets fishing further afield as the distribution of tuna shifts to the east.

Environmentally-friendly fishing operations (win-win): Minimizing the effects of existing fishing operations, and those projected to occur as tuna move east, on non-target species will help meet the requirements of certification schemes. Emissions of CO_2 from vessels and canneries should also be minimized to reduce the carbon footprint of industrial fisheries.

Safety at sea (win-win): Safety audits of longline vessels and any purse-seine vessels operating within the cyclone belt should help achieve acceptable standards for safety at sea in the event of more severe cyclones.

Climate-proof infrastructure (lose-win): Constructing new wharfs for fishing fleets and fish processing facilities designed to prevent inundation by rising sea levels and withstand the effects of more severe cyclones should safeguard investments in necessary infrastructure.

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 Western and Central Pacific Fisheries Commission (WCPFC) and Inter-American Tropical Tuna Commission (IATTC). A merger of these organizations 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 reorganization are likely to exceed the advantages initially, but the benefits are expected to outweigh these costs as the distributions of tuna species change.

The policies required to pave the way for the adaptations needed to reduce the risk of climate change to the benefits that Pacific Island economies receive from tuna, and capitalize on the opportunities, are provided by Bell *et al*. (2011d) and include:

- Promoting transparent access agreements between PICTs and DWFNs so that allocations under the VDS (and other fishing effort schemes) are understood by all stakeholders; and strengthening national capacity to implement these schemes.
- Adjusting national tuna management plans and marketing strategies to provide more flexible arrangements to sell tuna, or acquire tuna needed for local processing operations.
- Including the implications of climate change in the future management objectives of WCPFC.
- Requiring all industrial tuna vessels to provide operational-level catch and effort data to improve the models for estimating the redistribution of tuna stocks.
- Finalizing the declaration of national ocean boundaries in compliance with UNCLOS.
- Applying national management measures to address the implications of climate change for subregional concentrations of tuna in national archipelagic waters beyond the mandate of WCPFC.
- Developing further measures to mitigate the capture of bigeye tuna by purse-seine vessels.
- Using regional trade and preferential access agreements to market environmentally-friendly tuna products, and develop distribution channels that minimize CO_2 emissions.

4.2 Food security

The adaptations and suggested policies for maintaining the important role of fish for food security in PICTs centre on minimizing the size of the gap between the fish required for good nutrition and the fish available to coastal and urban communities through: 1) appropriate management of coastal (and freshwater) fish habitats and stocks; 2) increasing access to tuna; and 3) boosting freshwater pond aquaculture.

Some of these interventions are not new – they have been proposed for many years as an integral part of effective coastal zone management and a community-based ecosystem approach to fisheries management (CEAFM) (FAO, 2003; SPC, 2010), and to address the effects of population growth on the availability of fish for food security (Bell *et al*., 2009). The CEAFM co-management framework, which integrates customary marine tenure and other social capital, local governance, traditional knowledge, self-interest and self-enforcement capacity, provides the most effective way to implement many of these adaptations. This is particularly the case when the adaptations include the principles of 'primary fisheries management' (Cochrane *et al*., 2010) and are considered by cross-sectoral management advisory groups comprised of both government and non-government members.

The priority adaptations are described in detail by Bell *et al*. (2011d) and summarized below.

<u>Manage and restore vegetation in catchments (win-win)</u>: Increasing vegetation cover in catchments will reduce the transfer of sediments and nutrients to rivers and coasts after heavy rain and help prevent damage to the coral reefs, mangroves, seagrasses and intertidal flats supporting coastal fisheries.

Foster the care of coastal fish habitats (win-win): Preventing pollution and managing waste in coastal areas to maintain water quality, and eliminating damage to coral reefs, mangroves and seagrasses (e.g. by destructive fishing methods, gathering building materials and poorly-designed tourist activities), will help build resilience of coastal fish habitats to climate change.

Provide for landward migration of coastal fish habitats (lose-win): Prohibiting construction of buildings on low-lying land adjacent to mangroves, seagrasses and intertidal flats, and installing wide culverts beneath existing roads, will allow low-lying areas to become fish habitats as sea levels rise.

Sustain production of bottom-dwelling fish (lose-win): Maintaining the replenishment potential of stocks through more conservative fishing practices will help reduce the gap between coastal fisheries production and the fish needed by rapidly growing populations.

Diversify catches of bottom-dwelling fish (lose-win): Taking catches representative of the changes in abundance of the fish that result from climate change will help optimize the potential production from coastal fisheries.

Increase access to tuna for coastal communities (win-win): Developing small-scale fisheries for tuna is a major adaptation for maintaining the important contributions of fish to food security in the region (see Box 1 for the most practical ways of doing this for coastal communities).

Increase access to the industrial tuna catch and bycatch (win-win): Promoting the storage and distribution of low-value tuna and bycatch from industrial vessels transhipping their catch at major ports will provide inexpensive fish for rapidly-growing urban populations. This adaptation is now facilitated by a PNA management regulation banning the discarding of small tuna at sea.

Develop coastal fisheries for small pelagic species (win-win?): Increasing the catch of mackerel, anchovies, pilchards, sardines, scads and fusiliers will improve access to fish for food security and livelihoods. It remains to be seen how the projected increased stratification of the ocean (which reduces the productivity of food webs supporting these planktivorous species) interacts with increased runoff around islands from higher rainfall (which would increase productivity) to determine the abundance of these fish.

Develop appropriate models for expansion of freshwater pond aquaculture (win-win): Identifying the hatchery systems and networks that allow high-quality juvenile fish to be distributed to both small-scale and large-scale farmers, and secure the supplies of cost-effective feeds required for semi-intensive and intensive farming systems, will help freshwater pond aquaculture fulfil its potential now, and under more favourable future conditions.

Improve post-harvest methods (win-win): Training communities, particularly women, in appropriate ways to improve traditional smoking, salting and drying methods will extend the shelf life of fish when good catches are made.

The policies required to support adaptations needed to reduce the risk of climate change to the contributions that fish makes to food security in PICTs, and make the most of the opportunities, are described by Bell *et al.* (2011d) and include:

- Strengthening governance for sustainable use of all coastal fish habitats by: building the capacity of management agencies to understand the threats posed by

climate change; empowering communities to manage fish habitats; and changing agriculture, forestry and mining practices to prevent sedimentation and pollution.
- Protecting source and resilient coral reefs supplying recruits to fish populations on 'downstream' reefs to help these reefs recover after coral bleaching or cyclones.
- Minimizing barriers to landward migration of coastal habitats during development of strategies to assist other sectors respond to climate change.
- Promoting mangrove replanting programmes in suitable areas to meet the twin objectives of enhancing habitat for coastal fisheries and capturing carbon.
- Applying CEAFM and 'primary fisheries management' to stocks of coastal fish and shellfish to maintain their potential for replenishment.
- Restricting export of coastal bottom-dwelling fish to ensure that these resources are available for national food security where necessary.
- Increasing access to tuna for the food security of coastal communities where required by reducing national allocations to industrial fleets.
- Including anchored inshore fish aggregating devices (FADs) as part of the national infrastructure for food security (Box 1), and making provision for regular maintenance and replacement of FADs.
- Dedicating a proportion of the revenue from fishing licences to improve access to tuna for food security.
- Providing training and technical support for coastal fishing communities to catch small pelagic fish.
- Promoting the benefits of freshwater aquaculture based on Nile tilapia for supplying fish to growing inland communities and urban populations with poor access to other sources of animal protein, but limiting Nile tilapia farming to catchments where the Mozambique tilapia is already established to reduce any possible effects on freshwater biodiversity.
- Facilitating the training needed to operate freshwater pond aquaculture enterprises successfully.
- Developing partnerships with regional technical agencies to provide the necessary technical support for development of freshwater pond aquaculture.
- Revising primary school curricula to teach children about fish and food security, focusing on the importance of fish for their health; the basic management actions needed to maintain fish habitats and fish stocks; and the options for increasing future supplies of fish.

4.3 Livelihoods

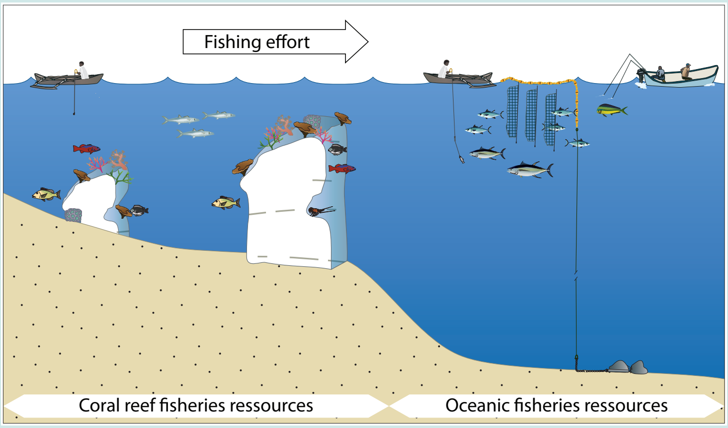
Many of the adaptations and suggested policies required to minimize the loss of livelihoods derived from fisheries and aquaculture activities, and to take advantage of the opportunities, are the same as those described in Sections 4.1 and 4.3. Examples include the imperative to conserve and restore fish habitats, the need to secure the supplies of tuna required to base more tuna processing operations within PICTs, switching coastal fishing effort from demersal fish to nearshore pelagic fish around inshore FADs and developing pond aquaculture in peri-urban areas. The additional adaptations needed to optimize the number of jobs that can be sustained by the sector are outlined below.

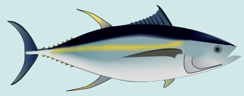
<u>Improve technical and business skills of communities (win-win)</u>: Providing training programmes to teach community members the necessary fishing and farming techniques, and small business skills, will assist them to participate in fishing around FADs and for small pelagic species, developing pond aquaculture and applying post-harvest methods. 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.

BOX 1

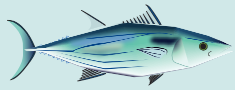
Promoting small-scale fisheries for tuna

A key adaptation for maintaining the contributions of fish to food security of coastal communities as productivity of coral reef fisheries declines is transferring fishing effort to nearshore pelagic fish, especially tuna.





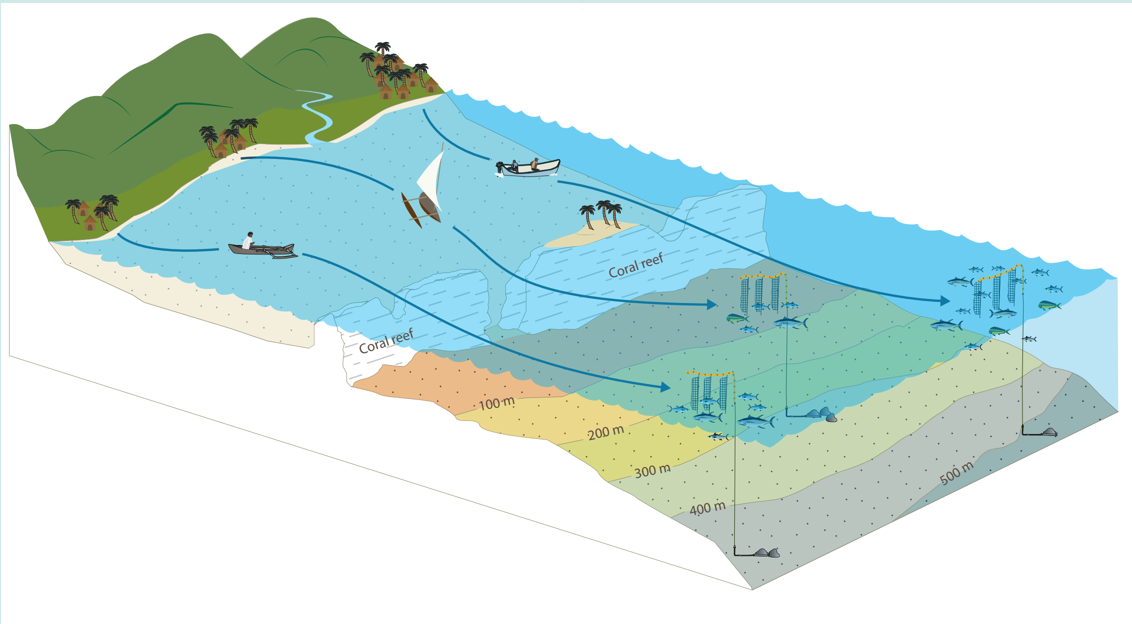
YELLOWFIN TUNA



SKIPJACK TUNA

Installation of anchored fish aggregating devices (FADs) close to the coast (usually within 1–6 km from the shore at depths of 300–1000 m) is often the most effective way of providing small-scale coastal fishers with better access to the abundant skipjack and yellowfin tuna resources of the region (SPC 2012a, b).

The design of inshore, anchored FADs has been developed over decades and works well, provided the FADs are placed where they attract mainly tuna and other oceanic fish, and not pelagic fish closely associated with reefs. The value of tuna and other large pelagic fish caught around inshore FADs can greatly exceed the costs of construction and deployment (Sharp 2011). Training in the methods used to fish around FADs (Preston et al. 1998), and post-harvest processing of catches, help communities maximise the benefits of this simple and effective technology. FADs need to be maintained regularly and replaced when lost. Networks of FADs should be an important part of the national infrastructure for food security in many Pacific Island countries and territories.



Rebuild populations of sea cucumbers and trochus (lose-win): Applying primary fisheries management (Cochrane *et al*., 2011) to make 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 (Friedman *et al*., 2008); and placing strict controls on the size of individuals exported, should help reverse the declines in stocks of these species. Robust stocks will have greater resilience to climate change and support more livelihoods.

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.

Diversify production of coastal aquaculture commodities (win-win): Assessing the potential to grow 'new' commodities in the region that are likely to 1) support profitable enterprises, and 2) be favoured by prevailing environmental, economic and social conditions in PICTs, could help maintain employment in the sector as other aquaculture commodities are affected by climate change or create new livelihoods.

Modify locations and infrastructure for coastal aquaculture (lose-win): Relocating pearl culture operations to sites where aragonite saturation levels remain high enough for adequate growth and survival of pearl oysters, and formation of high-quality pearls, could help maintain the profitability of pearl-farming enterprises. Raising the floor and wall height of shrimp ponds, and assessing which alternative commodities (perhaps sea cucumbers) could be produced in ponds no longer suitable for shrimp farming should also help retain or create jobs in the sector.

The policies required to support adaptations needed to reduce the risk of climate change to livelihoods and income-earning opportunities based on coastal fisheries and aquaculture are given in more detail by Bell *et al*. (2011d) and include:

- Providing access to the training needed to operate profitable businesses based on small-scale coastal fisheries and aquaculture activities for rural communities.
- Developing partnerships with regional technical agencies to provide the necessary support to manage coastal fisheries and develop aquaculture enterprises.
- Promoting 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.
- Informing prospective private sector investors in coastal aquaculture about the projected horizons for economically viable operations for each commodity under climate change.
- Providing incentives for aquaculture enterprises to assess risks to infrastructure so that farming operations and facilities can be relocated if necessary.
- Strengthening 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.

4.4 Gaps in knowledge

Much uncertainty still surrounds the vulnerability assessment for the fisheries and aquaculture sector reported by Bell *et al*. (2011a). Apart from the need to improve and downscale global climate models so that they provide robust projections of changes to surface climate and the ocean at scales meaningful to management in PICTs, uncertainty can be reduced by filling gaps in the knowledge of fish habitats and fish biology.

The outstanding contributions of tuna to economic development and the increasing role that tuna will need to play in providing food security in urban and coastal areas make research on tuna imperative. However, where coastal communities have a high dependence on coastal fisheries, the various steps needed to improve the resilience of these resources also merits quick and sustained action. Arguments can also be made for timely research on freshwater fisheries and pond aquaculture to improve the food security of the large and rapidly growing inland populations of PNG. The specific research needed is described in detail by Bell *et al*. (2011d) and summarized below.

Fish habitats

Open-ocean food webs

The extent to which climate change is likely to affect food webs for tuna in the tropical Pacific Ocean is still poorly understood. More long-term time-series data are a priority. Better biogeochemical models will also pave the way for improved application of ecosystem models (e.g. SEAPODYM) (Lehodey *et al*., 2011) to project the effects of changes in components of the food web on local abundances of tuna.

To parameterize the biogeochemical models needed to improve our confidence in simulations of tuna catches under a changing climate, research is needed to:

- assess the effects of higher CO_2 concentrations on the carbon-to-nitrogen ratio of organic matter in the ocean;
- identify whether changes in the Equatorial Undercurrent will deliver more iron to the equatorial upwelling and help overcome the iron limitation to primary productivity there;
- determine the variability in abundance of micronekton across the region by validating acoustic methods; and
- evaluate the extent of lateral transport of organisms from the equatorial upwelling to the Warm Pool.

Coral reefs

The key research questions for these important coastal fish habitats include identifying:

- effects of ocean acidification and warming on the relative balance between calcification and erosion, and on the coral cover and benthic composition of coral reef habitats;
- any negative synergies between projected increases in SST, ocean acidification and nutrient loads, and possibly more powerful waves from stronger tropical cyclones;
- likely consequences for coral reefs of a very rapid rise in sea level; and
- the coral reef habitats likely to have the greatest natural resilience to bleaching, ocean acidification and other impacts of climate change.

Mangroves and seagrasses

There are still major gaps in our knowledge of the distribution, diversity and coverage of mangrove and seagrass habitats across the tropical Pacific. In addition to providing/checking estimates of habitat area, the following information is needed to improve our understanding of the vulnerability of these habitats:

- sensitivity of mangroves to sea-level rise and rates of sedimentation;
- sensitivity of seagrasses to changes in temperature, turbidity, terrestrial runoff and sea level rise; and
- locations where mangroves and seagrasses are likely to have greater natural resilience.

Freshwater rivers

Ecosystem models for representative river types need to be developed because little is known about freshwater rivers in the region. Important first steps are to quantify and map the habitats created by rivers and estuaries to set benchmarks for identifying changes in habitat area and quality.

Fish stocks and aquaculture

Tuna

To improve confidence in projected future catches of tuna simulated by the SEAPODYM model (Lehodey *et al*., 2011), research is needed to:

- identify the likely effects of variation in temperature, O_2 and ocean acidification on the vertical distribution of tuna and their vulnerability to capture by different gear types; and
- assess the carrying capacity of the pelagic ecosystem in the tropical Pacific for tuna based on: energy transfer efficiency between all levels of the food web; spatial and temporal variation in micronekton; better description of tuna diets; and the influence of nutrient-rich coastal waters as feeding areas for tuna.

Reporting of tuna catches on the high seas at the same spatial scale as reporting of catches in EEZs is also needed to improve the parameterization of the SEAPODYM model.

Coastal fisheries

Improved knowledge of the likely effects of climate change on the production of coastal fisheries depends on research to:

- identify the responses of target fish species to projected changes in structural complexity and biological diversity of coral reefs;
- investigate the role of mangroves and seagrasses as nursery and feeding areas for bottom-dwelling fish, and their links with coral reefs;
- assess the sensitivity and adaptive capacity of target fish species to changes in SST and pH, including effects on early life history stages; and the combined effects of these variables and their interactions with other stressors;
- model the effects on larval dispersal of decreases in the strength of the South Equatorial Current and the South Equatorial Counter Current;
- determine whether a link exists between the risk of ciguatera fish poisoning and climate change; and
- evaluate the likely effects of higher levels of nutrients from the projected increases in runoff around high islands on the productivity of small pelagic fish species.

Freshwater fisheries

Key questions for freshwater fisheries involve determining how the main species use various habitats at different stages of their life cycles, and their responses to changes in habitat availability and quality. Understanding interactions among fish species, including introduced and invasive species, and determining whether such interactions are likely to be affected by the projected changes to water temperature and flow rates, are also important areas of research.

Aquaculture

To capitalize on the expected enhanced opportunities for pond aquaculture, research and development is needed to:

- identify the 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; and

- identify the likelihood that warmer and wetter conditions may increase the risks posed to pond aquaculture by disease.

To reduce the risk to the major mariculture activities, research is required to:

- determine the likely effects of ocean acidification on survival of pearl oysters and formation of high-quality pearls, and identify whether microsites exist where the buffering effects of nearby coral reefs, macroalgae and seagrasses maintain aragonite saturation levels within the limits required by pearl oysters to produce high-quality nacre;
- assess whether the temperature fluctuations during the short 'spring' and 'autumn' seasons in New Caledonia that cause mortality of shrimp from viruses are likely to be reduced or accentuated in the future; and
- identify sites where seaweed can be grown efficiently in the future.

4.5 Institutional arrangements for implementing adaptations and policies

The region has strong frameworks for managing the transboundary fisheries for tuna, designed to conserve stocks and maximize the sustainable economic and social benefits from these valuable resources. Due to the isolation of most PICTs from one another (exceptions are the close proximity of islands in the Western Province of Solomon Islands to Papua New Guinea, and American Samoa and Samoa), coastal fisheries are managed on a national basis, usually by dedicated fisheries agencies. These national agencies also have responsibility for managing aquaculture activities and enterprises.

The national agencies have policies for optimizing sustainable benefits from the sector. These policies are revised periodically, which provides an opportunity to incorporate priority climate change adaptations (CCA). However, implementing the priority adaptations is not always easy due to limited national capacity of many PICTs. This is less of a problem for the tuna industry due to the strong assistance available to PICTs for managing oceanic fisheries (see below). In the case of coastal fisheries, many PICTs will need to rely on NGOs and regional partner agencies to implement priority adaptations at the community level.

National fisheries agencies would also benefit from assistance to convey priority adaptations and policies for the sector to national planning authorities to ensure that they are embedded in National Action Plans. This is particularly important for coastal and freshwater fisheries, where there are severe risks that adaptations designed to assist other sectors, e.g. infrastructure, could result in maladaptation for these fisheries through the loss of fish habitat. Maintaining the potential for freshwater fish habitats to expand as river flows increase and for coastal fish habitats to migrate landward during sea-level rise requires strong oversight. A key feature of SPC's climate change strategy is to appoint staff in PICTs to assist national planning authorities to integrate and rationalize the priority adaptations of all sectors in the development of National Action Plans.

The main frameworks and approaches used to manage oceanic, coastal and freshwater fisheries, and aquaculture, in the region are summarized below.

Oceanic fisheries

Arrangements for cooperative management of the region's transboundary tuna resources were launched in 1979, with the formation of FFA, which coordinates policy advice and technical support to assist members of the Pacific Islands Forum manage fishing effort by DWFNs and domestic fleets within their EEZs. FFA implements a 'Regional Tuna Fisheries Management and Development Strategy' 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 (FFA, 2009). The key management measures and treaties developed by FFA for its members are summarized in Table 21.

TABLE 21
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.
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.
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.
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.

* Measures now transferred to PNA.

Due to the fact that about 40 percent of the world's canning tuna catch comes from the EEZs of PNA members, purse-seine fishing effort across these zones is allocated by the Director of the PNA Office through the vessel day scheme under amendments to the Palau Arrangement (Table 21). The PNA Office also explores collective ways to increase the contributions of tuna resources to the economic development of its members. In a similar move, the Polynesian countries have launched the Te Vaka Moana Arrangement (TVMA) to harmonize management approaches, exchange information and optimize the benefits from longline fishing for tuna in their EEZs.

In response to the need to manage tuna stocks across the entire WCPO, the Convention for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean was declared in 2004. WCPFC was established to administer this convention. PICTs 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.

Examples of management measures implemented by PNA members and supported by FFA and WCPFC to reduce fishing for bigeye tuna by 30 percent, and by 10 percent for yellowfin tuna, to avoid the possibility of these stocks becoming overfished include: 1) a ban on fishing around drifting fish aggregating devices (FADs) for several months each year; 2) a fishing closure for the high seas pockets adjacent to their EEZs; 3) prohibiting discarding of undersized tuna at sea; and 4) placement of observers aboard all purse-seine vessels.

These management arrangements are underpinned by regular stock assessments for all four species of tuna (SPC, 2012b). These stock assessments involve collection of data on catch and fishing effort, and biological research and tagging studies by SPC's Oceanic Fisheries Programme[9]. Research is also underway on the food webs that support tuna (Lehodey *et al*., 2010; Allain *et al*., 2011), and the effects of industrial tuna fisheries on the bycatch of other large pelagic fish (Fitzsimmons, 2010).

[9] www.spc.int/oceanfish

Coastal fisheries

Frameworks and approaches for managing coastal fisheries in the region differ substantially from those used for the industrial tuna fisheries for two main reasons 1) coastal fisheries are based on hundreds of species of demersal fish and invertebrates (Dalzell *et al*., 1996; Pinca *et al*., 2011; Pratchett *et al*., 2011), very few of which yield catches great enough to justify formal stock assessments; and 2) self-replenishing populations of most coastal species are restricted to individual PICTs. These features of coastal fisheries, combined with the limited scientific capacity in many national fisheries agencies, have resulted in much uncertainty about the sustainable harvest levels and status of coastal fisheries. Exceptions are the component of the nearshore pelagic fishery comprising skipjack and yellowfin tuna caught by subsistence and small-scale fishers (see above); and the sea cucumbers and trochus targeted for export, which are known to be overfished in many PICTs (Friedman *et al*., 2008; Pratchett *et al*., 2011).

Strengthening community-based management is broadly seen as offering the best hope of securing coastal fisheries resources for the future (Gillett and Cartwright, 2010; SPC, 2010; Pomeroy and Andrew, 2011).

The onus is on all stakeholders to address habitat degradation caused by agriculture, forestry and mining activities in catchments (Gehrke *et al*., 2011a; Hoegh-Guldberg *et al*., 2011; Waycott *et al*., 2011), and overfishing due to population growth and other economic and social drivers (Gillett and Cartwright, 2010; Kronen *et al*., 2010; Allison *et al*., 2011; Hall *et al*., 2011).

To this end, a 'community-based ecosystem approach to fisheries management' is being developed for the region (SPC, 2010). CEAFM merges the well-recognized need for an ecosystem approach (FAO, 2003; Preston, 2009) and primary fisheries management (Cochrane *et al*., 2011) and should be facilitated by long-standing customary marine tenure in much of Melanesia (Ruddle *et al*., 1992; Kuemlangan, 2004). Primary fisheries management recognizes the need to use simple harvest controls, such as size limits, closed seasons and areas, gear restrictions and protection of spawning aggregations, to maintain the replenishment potential of stocks. Investments in the social capital and institutions needed for communities and governments to manage coastal fisheries using this framework (Pomeroy and Andrew, 2011) are needed to improve the likelihood that priority adaptations to climate change will be implemented effectively.

Freshwater fisheries

Primary fisheries management implemented through CEAFM is also needed to maintain the benefits of fisheries for communities living beside rivers and lakes in Melanesia, particularly in PNG. Investments in primary fisheries management in freshwater ecosystems are expected to occur under conditions more favourable to fisheries production, provided catchments are managed appropriately. As the areas available for catching freshwater fish expand, it will be important to maintain traditional access and ownership rights. But agencies with responsibilities for freshwater fisheries must also rationalize the effects of invasive fish species. The freshwater fish fauna in PNG already includes a high proportion of introduced and invasive species and although many of these species are valued as food, other unwanted invasive species are reducing the availability of native fish species and the preferred introduced species (Gehrke *et al*., 2011b).

Aquaculture

The mature pearl and shrimp farming industries in the region are managed under established government regulations (Ponia, 2010; Pickering *et al*., 2011). However, the diverse range of exploratory and emerging aquaculture activities are generally operating under much looser management frameworks (SPC, 2007; Gillett, 2009). As existing activities develop and other economically viable prospects for aquaculture are identified, 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 (FAO/NACA, 2000; SPC, 2008c; OIE, 2010); 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.

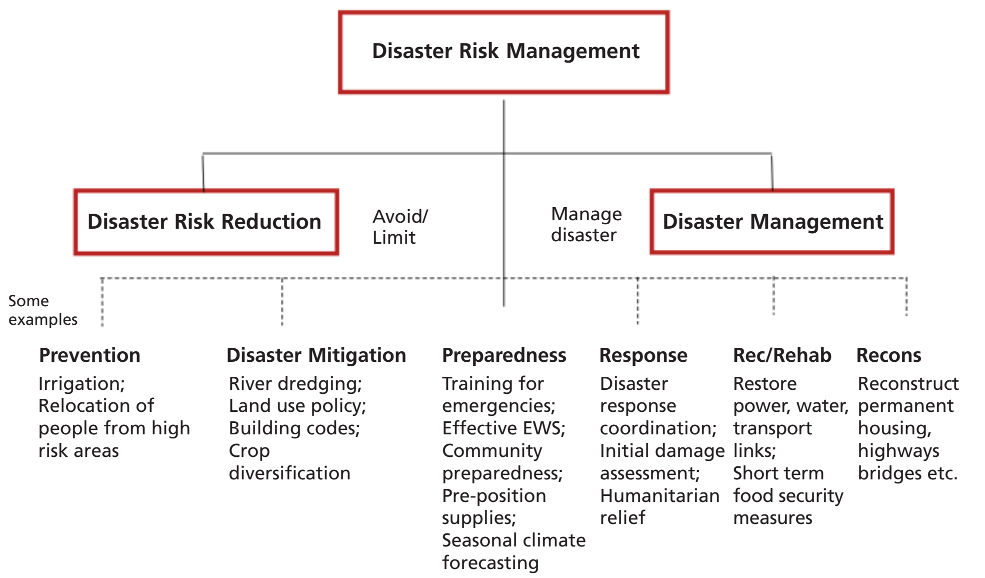
4.6 Integrating climate change adaptations with disaster risk management

Disaster Risk Management (DRM) is defined as 'the systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster' (UNISDR, 2009). The IPCC defines DRM as 'the processes for designing, implementing and evaluating strategies, policies and measures to improve the understanding of disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, response and recovery practices, with the explicit purpose of increasing human security, well-being, quality of life, resilience and sustainable development' (Field *et al*., 2012).

Common examples of activities or measures linked to DRM are: development and implementation of flood management systems; enforcement of building codes; introduction of disease resistant varieties; implementation of end-to-end early warning systems; development and use of risk databases and other information collections to inform DRM and development decision-making; development and implementation of emergency response plans; and risk-sensitive recovery and reconstruction following disasters. A simple representation of DRM is shown in Figure 13.

Globally, the concepts of DRM and CCA have now been closely linked. Both concepts attempt to address underlying causes of vulnerability and risks to sustainable national development caused by geophysical or climate-related hazards, whether they be slow or sudden-onset in nature. Combining DRM and CCA is particularly

FIGURE 13
Disaster risk management: a Pacific representation



pertinent in the Pacific, where there is a large overlap between the most common natural disasters and the impacts of climate change on the fisheries and aquaculture sector, i.e. cyclones and floods.

Both DRM and CCA strive towards a similar end-point. This has already been recognized by a number of PICTs, including Tonga, Cook Islands and Tuvalu, which have integrated their strategic approaches to both types of risks through Joint Climate Change and DRM National Action Plans (JNAPs).

In this section, the changes in governance of DRM in the Pacific, required by the increased integration of disaster and climate risk management interventions through national planning and finance institutions, are discussed. It attempts to demonstrate that, within the context of natural hazard risks and the ongoing challenge of sustainable development, the constrained bureaucracies of PICTs must be more innovative. In particular, PICTs must revise their institutional arrangements to ensure disaster and climate risk are central policy rather than relegate them within the traditional DRM establishment.

Such reforms are urgent because the Pacific is one of the most vulnerable regions in the world to natural disasters. Of the top 20 countries with the highest average annual losses to GDP from disasters, eight are PICTs. Since 1950, extreme events have affected approximately 9.2 million people in the Pacific with 9 811 reported deaths and damage of USD3.2 billion (World Bank, 2012).

The move to mainstreaming

To assist Pacific Island countries increase their safety and resilience to natural disasters, Pacific leaders approved the Pacific Disaster Risk Reduction and Disaster Management Framework for Action 2005–2015 (RFA) in October 2005. This policy instrument, based on the global Hyogo Framework for Action 2005–2015, identifies a range of regional and national activities that can be implemented to increase safety and resilience.

The RFA is closely linked to the Pacific Plan – the strategic regional platform to promote economic growth, sustainable development, good governance and security. Pacific Leaders acknowledge that the inextricable link between disaster and development, in particular that the challenges of ensuring food and water security, housing, health and education can be adversely affected by a disaster. Leaders also understand that poor development practices can increase the vulnerability and risk to disaster. Accordingly, implementation of the RFA is embedded under the 'Sustainable Development' strategic objective of the Pacific Plan.

As of July 2012, 13 PICTs have elected to pursue strategic national action plans for DRM and CCA with only PNG, given its size and related challenges, opting to pursue a 'DRM Mainstreaming Programme' which has resulted in the development of a joint DRM and CCA Action Plan at a provincial level for the Morobe Province. Table 22 summarizes the recent status of NAP/JNAPs in the Pacific.

The RFA has highlighted the need for PICTs to mainstream disaster risk considerations into national planning and budgetary systems because these processes are the major vehicles through which sustainable national development aspirations are realized. The need for mainstreaming has been consistently reaffirmed in the Pacific in the period since the RFA was adopted. During the annual meetings of the Pacific's 'disaster' community under the umbrella of the Pacific Platform for DRM, mainstreaming has been highlighted as a significant priority alongside advocacy, governance, the need for baseline data and information, training and education, community level support, risk financing and others[10].

DRM mainstreaming requires a multifaceted approach and multistakeholder involvement. No single government agency can have the sole responsibility to integrate

[10] See Key Outcomes Statement of the 2011 Pacific Platform for DRM.

TABLE 22
Status of National Action Plans for Climate Change (NAPs) and Joint Climate Change and Disaster Risk Management National Action Plans (JNAPs) in July 2012

Country	NAP/JNAP
Cook Islands	DRM NAP developed in 2008. JNAP developed and endorsed by Government in 2011
Federated States of Micronesia	JNAP development to commence in 2012
Fiji	JNAP development in 2 phases on going from 2011.
Kiribati	DRM governance arrangements reviewed as a first phase of NAP development. Potential for JNAP
Marshall Islands	DRM NAP developed in 2007. JNAP developed in 2010/2011 and awaiting Government endorsement
Nauru	JNAP development commenced in April 2012 and still on going
Niue	JNAP developed and to be finalised before September 2012
Palau	JNAP development commenced in June 2012 and targeted for completion in early 2013
Papua New Guinea	DRM Mainstreaming Programme endorsed in May 2010 and undergoing implementation. Joint DRM and Climate Change Action Plan developed at provincial level in Morobe Province in 2011
Samoa	DRM NAP developed in December 2011
Solomon Islands	JNAP development process commenced in Deember 2011 and targeted for completion by December 2012
Tonga	JNAP developed and endorsed by Government in 2010 and undergoing implementation
Tuvalu	JNAP developed and endorsed by Government in 2011/2012
Vanuatu	DRM NAP developed and endorsed by Government in 2006. JNAP development process commenced in 2012.

disaster and climate risk into planning and budgetary systems. However, while there is a significant amount of rhetoric regarding multi-stakeholder approaches to DRM, the reality in many government systems in the Pacific is that the responsibility is often given to small, under-resourced National Disaster Management Offices by virtue of existing administrative and legislative arrangements. However, such arrangements are outdated and fail to recognize that addressing disaster and climate risk is principally a development issue. The reduction of disaster and climate risks can be more easily addressed by targeting the root causes of vulnerability and increasing resilience. Within a typical bureaucracy, this is led by central agencies like finance and planning and supported by departments responsible for the different sectors.

Existing institutional arrangements

Incorporating DRM within administrative directions/plans and legislation (e.g. Fiji's National Disaster Management Plan, 1995; Marshall Islands Disaster Assistance Act, 1987) entrusts the responsibility for DRM to National Disaster Councils or Committees. These Councils/Committees generally have high-level representation from all agencies in government, often a Permanent Secretary or Chief Executive. However, these large fora do not always meet regularly to discuss DRM and in particular disaster risk reduction (DRR).

The National Councils/Committee may meet following a hazard warning and/or during a disaster response but meetings are not usually frequent enough to discuss issues related to preparedness and response measures. There is also often inconsistency in or lack of decision-making at meetings due to delegation to subordinate staff, compounding the problems caused by the infrequency of meetings.

In PICTs with limited national capacity, assignment of responsibility for DRM to National Disaster Councils/Committees has placed a heavy burden on National Disaster Management Offices (NDMOs). Across the Pacific, NDMOs have also inherited the responsibility for DRR because sectoral agencies are either unaware or do not understand clearly their roles and responsibilities. The same can be said of non-state actors who also have a defined role for DRR and disaster management in some plans/legislation (e.g. Fiji NDMP, 1995). Even where these roles and responsibilities are understood, there is generally a lack of coordination and communication between sectoral agencies and NDMO so that any initiatives being undertaken in DRM may not be reported.

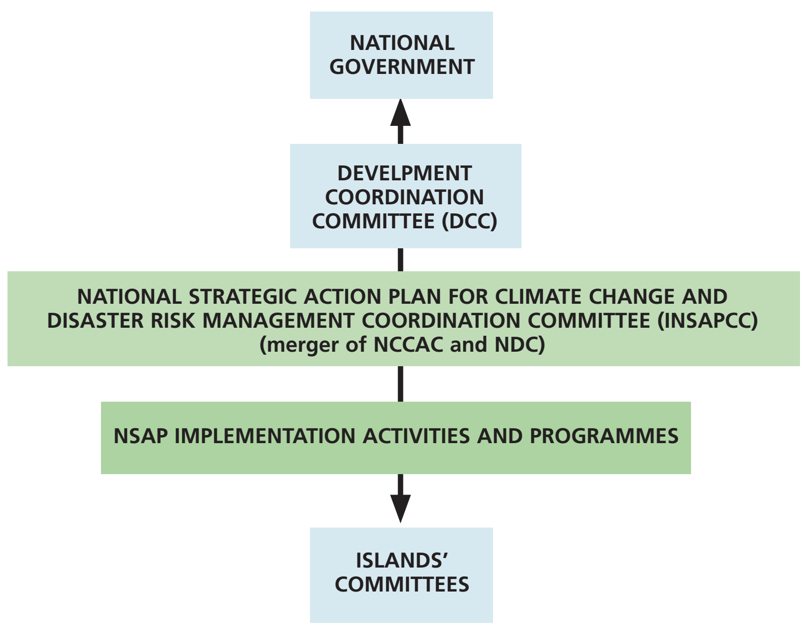
National Disaster Councils/Committees continued to have the lead responsibility for NAP/JNAP implementation, and disaster and climate risk remained institutionalized within the DRM and environment settings instead of within the 'development' sphere, where more stakeholders (including vulnerable groups) are regularly consulted.

The perceived lack of action or limited progress in DRM is often unfairly assigned to the NDMOs. These relatively small units within government systems take the blame for limited progress. However, change is taking place.

Mainstreaming and the 'new guard'

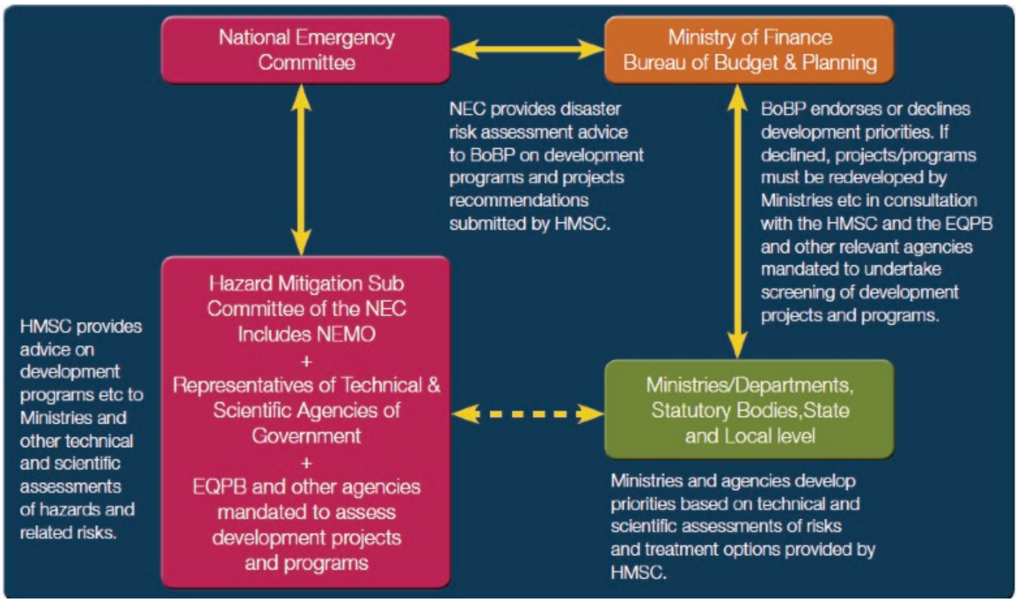
The pendulum is now swinging in disaster and climate risk reform in the Pacific. Recent national mainstreaming initiatives for DRM and CCA to develop strategic remedial actions have involved multi-stakeholder representation to identify the range of hazards, related issues of vulnerability and risk, and their root causes. Pacific governments, with the NDMOs and environment agencies as the lead focal points for NAPs/JNAPs, have embraced the need for contributions from a wide range of actors at national and subnational levels. As more countries venture into national disaster and climate risk mainstreaming they have become more receptive to placing discussion on these issues on centre-stage within established national development forums. In the case of Tuvalu, for example, under the National Strategic Action Plan (NSAP) for Climate Change and DRM 2011–2015, the overall responsibility for implementation is under the Development Coordination Committee of the Government. It provides the link to Cabinet for a technical committee for the NSAP (Figure 14).

FIGURE 14
Implementation structure for Tuvalu's national strategic action plan for climate change and disaster risk management



Also moving in this direction, Palau finalized its National DRM Framework in 2010 even though it does not have a JNAP in place. Under the framework, the arrangements Palau has established for DRR clearly specify a role for the Ministry of Finance's Bureau of Budget and Planning (Figure 15). The Bureau is seen as the national mechanism to confirm that DRR has been considered in national development programmes, either through development projects or sectoral plans, before making decisions on budget or resource allocation.

FIGURE 15
Palau's national disaster risk framework



The reform in Palau is significant. While Palau still gives its National Emergency Committee prominence in discussions on disaster risk issues, the elevation of the Ministry of Finance's role in DRR signals a 'changing of the guard' for DRM (and specifically DRR) and CCA. With support from internal and external partners, Palau is poised to move to the next level of DRM reform – institutionalizing disaster and climate risk within development planning and budgeting systems at State and community level. Such reform provides further opportunities for the needs of the most vulnerable groups to be addressed. Neverthelss, shifting of DRR oversight to a central agency like the Ministry of Finance and Planning requires reassessment of the core NDMO roles so that efforts and limited resources can be focused on strengthening disaster/emergency preparedness and response coordination capacity.

In summary, Pacific Island countries are now pursuing initiatives to mainstream disaster risk considerations into planning and budgetary systems at national and subnational levels. Mainstreaming initiatives are helping to redefine the institutional arrangements – there is a move towards 'centralized' leadership of DRM and Climate Change Adaptation within strategic national agencies, such as Ministries of Finance, Planning and Prime Minister's Office. As a result, the traditional role of providing overall DRM support by National Disaster Management Offices is being revised. The 'changing of the guard' for DRR and CCA coordination to a 'central agency' helps to higlight the issues of disaster and climate risk to development and rationalize recommended responses from the fisheries and aquaculture sector, where many of the risks from climate changes (cyclones and floods) are the same as those facing DRR efforts.

5. Recommendations

Investments are now needed by PICTs and their development partners at several levels to maintain the important contributions that fisheries and aquaculture make to the economies and communities as the climate of the region changes. Investments needed at the national level include:

- launching the adaptations that PICTs see as priorities to address the threats associated with climate change and other drivers to economic growth, government revenue, food security and livelihoods, and maximize opportunities (Sections 4.1–4.3);
- filling the gaps in knowledge required to improve our understanding of vulnerability;
- monitoring the projected effects of climate change on fisheries and aquaculture, and the success of adaptations; and
- strengthening partnerships to assist PICTs to maximize the returns on the investments listed above.

Investments are also needed to transfer the information from the recent regional vulnerability assessments (Bell *et al.*, 2011a) to communities and to support them to understand and apply the results. Frameworks for practical community-based approaches that should help integrate the analysis and governance required for effective management are provided by Johnson and Welch (2010), Miller *et al.* (2010), Cochrane *et al.* (2011), and Andrew and Evans (2011).

The key investments are described by Bell *et al.* (2011d) and summarized below.

5.1 Launching priority adaptations

Economic development and government revenue

- Full implementation of the vessel day scheme for the purse-seine and 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 an EPA with the EU by those PICTs canning tuna (PNG, Fiji and Solomon Islands) to help secure future supplies of tuna for their canneries.
- Establishment of competent authorities for fishery product food safety, and systems for demonstrating compliance with IUU fishing regulations, in PICTs supplying tuna to canneries in those countries with an EPA 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.

Food security and livelihoods

- Integrated land use planning to stabilize soils and prevent high sediment loads from entering streams and reaching the coast, including revegetation of areas in catchments most likely to intercept sediment, and establishing well-vegetated riparian buffer zones. Revegetation will not only reduce the vulnerability of fish habitats, it will help mitigate CO_2 emissions through carbon sequestration.

- Development of National Action Plans which integrate the protection of freshwater and coastal fish habitats (coral reefs, mangroves, seagrasses) with adaptations by other sectors to climate change; and identify the modifications to infrastructure needed to allow mangroves and other coastal fish habitats to migrate landward as sea level rises.
- Capacity-building of fisheries agencies and management advisory groups to assist communities to implement CEAFM.
- 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.
- Economic analyses to determine the relative benefits of allocating a proportion of estimated sustainable national tuna catch to subsistence and small-scale commercial fishers, compared with allocating it all to DWFNs or domesticating the industry.
- 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, together with cost-benefit analyses of producing canned tuna for local and export markets.
- 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.
- 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 develop small-scale commercial fisheries around FADs and for small pelagic fish species; expand pond aquaculture; and scale-up post-harvest processing.
- Training and capacity building for coastal communities, especially women, to engage in income-earning opportunities created by diversifying food production systems.
- Analysis of carbon footprints of the main aquaculture operations, and identification of better ways to conserve energy along the supply chain.

5.2 Filling gaps in knowledge

Tuna 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; and 2) incorporate socio-economic scenarios likely to drive future fishing effort in the region.
- Development, parameterization and verification of several biogeochemical models of the tropical Pacific Ocean, including collection of data on variability of nutrients, O_2, 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 logbooks of all vessels fishing on the high seas to determine the exact locations where tuna are caught in the tropical Pacific Ocean (includes developing rules for releasing data, e.g. timelags);
  - establishing long-term monitoring stations for physical and chemical ocean

variables in all five ecological provinces of the tropical Pacific Ocean to provide the data time series needed to force and validate ecosystem models;
– adding biochemical and acoustic sensors to the Tropical Atmosphere Ocean (TAO) array of moorings in the Warm Pool and PEQD, and/or to autonomous profiling floats such as the Argo array[11], with automatic data transmission to provide key missing data on variation in zooplankton and micronekton;
– continuing the satellite remote sensing of SST and chlorophyll *a* (Maes *et al*., 2010), 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 functional 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[12];
– supporting observers on industrial tuna vessels to sample micronekton from the stomachs of tuna and other top predators;
– conventional and electronic tagging programmes for tuna to verify projected changes in distribution in response to altered nutrients, water temperatures, currents and O_2 levels, and
– laboratory experiments to assess the effects of temperature extremes, O_2 deficits and ocean acidification on survival of tuna larvae and behaviour of adult tuna.

- 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.

Coastal fisheries

- Sampling programmes to determine how spatial and temporal variation in SST, ocean acidification, turbidity and storm surge affect the three-dimensional architecture of the coral reefs that support bottom-dwelling fish and shellfish.
- Modifying the satellite products provided by the National Oceanic and Atmospheric Administration to provide the finer-scale measurements (<1 km) needed to manage individual reefs; and integrate data on light intensity, pH and turbidity with SST.
- Mapping mangroves and seagrasses 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.
- Producing higher-resolution topographic maps to identify more accurately the projected losses of mangroves blocked from migrating landward by infrastructure, and the areas to be inundated that have potential for colonization by mangroves and seagrasses.
- Assessing 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;
- Determining whether the incidence and virulence of ciguatera fish poisoning is likely to vary as SST increases, and as coral cover decreases and macroalgae increase.
- Evaluating the possible effects of increased runoff from high islands on the abundance of small pelagic fish species.

[11] www.argo.ucsd.edu
[12] See www.imber.info/CLIOTOP_MAAS.html for more details.

Freshwater fisheries

- Flood modelling to identify likely changes to floodplain fish habitats to allow national planners to provide for increased fisheries production when developing cross-sectoral strategies to adapt to projected increases in rainfall.
- Developing 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; and 3) improved projections of flow rates, nutrient loads, water temperature and dissolved oxygen from downscaled global climate models.

Aquaculture

- Impact risk assessments for the introduction or further translocation of Nile tilapia for pond aquaculture to provide decision-makers with science-based advice about any possible effects on freshwater biodiversity. These assessments should ensure that any such potential effects are not confounded with habitat degradation, and are relative to any existing impacts on biodiversity attributed to Mozambique tilapia.
- Assessing how long existing shrimp ponds are likely to function efficiently as sea level rises.
- Determining the likely effects of ocean acidification on growth and survival of juvenile and adult pearl oysters, and pearl quality.

5.3 Localizing vulnerability assessments

Assist communities to make semi-quantitative evaluations of their vulnerability (Johnson and Welch, 2010) based on the information from the recent regional vulnerability assessment for the sector (Bell *et al*., 2011a). Such semi-quantitative evaluations should include:

- gender-sensitive evaluation of resource use and livelihood strategies by coastal communities to identify livelihood vulnerability and resilience with regard to projected climate change impacts;
- application of regional and local knowledge at a community level to identify and understand the specific sources of vulnerability;
- facilitation of widespread participation of 'grass-roots' stakeholders in community-based adaptation responses, supported by easy-to-use decision support systems, to minimize vulnerability; and
- training in culturally sensitive communication for scientists and managers to facilitate effective adoption of participatory principles during joint adaptive response projects with communities.

5.4 Monitoring changes in resources and the success of adaptations

Investments in a variety of monitoring programmes are required to assist PICTs to assess the status of their fisheries resources, determine whether the projected effects of climate change on these resources are occurring, and measure the success of adaptations. These investments include:

- 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 on board and transmitted to FFA and SPC via the vessel monitoring system;
- long-term monitoring programmes for coastal fisheries to 1) inform PICTs about changes in fish habitats and stocks (including market sampling); 2) determine 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; and

- modifications to household income and expenditure surveys and censuses to measure the success of adaptations (against socio-economic baselines) in maintaining the contributions of coastal fisheries and aquaculture to food security and livelihoods.

5.5 Strengthening 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 4.5; 2) fill the remaining gaps in knowledge; 3) localize vulnerability assessments; and 4) monitor the projected changes in resources and success of adaptations.

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. In the case of coastal fisheries, this will involve providing continued support to the scientific institutions, regional organizations and NGOs already assisting PICTs to implement CEAFM. Support for the continued development of the Global Partnership for Climate, Fisheries and Aquaculture (PaCFA)[13] should also be considered to ensure that lessons learned from other regions can be passed on to PICTs, and vice versa.

[13] www.climatefish.org

6. Conclusions

Overall, the Pacific Island countries and territories appear to be in a better position than nations in other regions to cope with the implications of climate change for fisheries and aquaculture. Although the changes in distribution and abundance of tuna projected from preliminary modelling are likely to require broader approaches for supplying existing and proposed canneries, and may eventually reduce GDP and/or government revenues slightly for a few countries in the western Pacific, the expected effects for the region as a whole are among the better possible outcomes. In particular, PICTs with the greatest dependence on tuna (e.g. Kiribati, Nauru, Tuvalu and Tokelau) are likely to receive greater benefits as the fish move east, whereas the projected decreases in production occur in those PICTs where industrial fishing and processing make only modest contributions to GDP and government revenue due to the relatively large size of their economies.

The tuna resources of the region also promise to provide PICTs with options to deliver access to the fish recommended for good nutrition (except for populations in inland PNG) as the projected production of coastal fisheries declines due to the direct and indirect effects of climate change (Section 3.4). This can be done by developing small-scale fisheries for tuna centred around networks of inshore FADs (Section 4.5). Even in countries like PNG and Solomon Islands, where abundances of tuna are projected to decline progressively, there should still be ample tuna to allocate for local food security.

The increased rainfall expected for the tropical Pacific also provides several PICTs with the opportunity to increase access to fish through pond aquaculture. This is likely to be most important for the inland populations in Fiji, PNG and Solomon Islands, and for the rapidly growing urban areas in these countries. Higher future rainfall and water temperatures are also expected to improve the production of freshwater fisheries in Melanesia.

The key challenges for the region are to:

1. 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.
2. 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.
3. 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 (Section 3.8), in ways that should be favoured by climate change.
4. Manage coastal aquaculture enterprises producing commodities for export and local markets to optimize 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 coastal fisheries – habitat degradation and overfishing. Investments in both the win-win and lose-win adaptations described in Section 4.5 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.

Nevertheless, uncertainty remains about the magnitude of the projected effects of climate change on the sector. This uncertainty will be reduced through development of improved global climate models downscaled to resolutions appropriate for the management of fish stocks and habitats. The investments described in Section 5 should 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.

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Annex 1

LAND AND EXCLUSIVE ECONOMIC ZONES

Land and exclusive economic zone (EEZ) areas for each of the 22 Pacific Island countries and territories (PICTs)

PICT	Land area (km²)	Area of EEZ* (km²)	Ratio land/sea (%)
Melanesia			
Fiji	18,272	1,229,728	1.464
New Caledonia	19,100	1,111,900	1.689
PNG	462,243	2,446,757	15.890
Solomon Islands	27,556	1,553,444	1.743
Vanuatu	11,880	668,220	1.747
Micronesia			
FSM	700	2,939,300	0.024
Guam	541	214,059	0.252
Kiribati	810	3,550,000	0.023
Marshall Islands	112	2,004,888	0.006
Nauru	21	293,079	0.007
CNMI	478	752,922	0.063
Palau	494	605,506	0.082
Polynesia			
American Samoa	197	434,503	0.045
Cook Islands	240	1,947,760	0.012
French Polynesia	3521	4,200,000	0.084
Niue	259	296,941	0.087
Pitcairn Islands	5	800,000	0.001
Samoa	2935	110,365	2.590
Tokelau	10	318,990	0.003
Tonga	699	676,401	0.103
Tuvalu	26	719,174	0.004
Wallis and Futuna	255	242,445	0.105
Total (average)	**550,354**	**27,116,382**	**(2.03)**

* The area between the territorial/archipelagic sea boundary and 200 nautical miles from the base points. This area denotes the 'Fisheries Zone' where a country does not have an EEZ.

Annex 2

POPULATION ESTIMATES AND PROJECTIONS

Population estimates for the 22 Pacific Island countries and territories (PICTs) for 2010, with projections to 2020 and 2035 (see www.spc.int/sdp for ongoing adjustments to population estimates and projections for each PICT)

PICT	Mid-year population estimate		
	2010	2020	2035
Melanesia	**8,654,200**	**10,465,000**	**13,492,371**
Fiji	847,800	890,400	977,600
New Caledonia	252,300	291,200	322,538
PNG	6,752,700	8,267,400	10,822,300
Solomon Islands	549,600	703,500	969,900
Vanuatu	251,800	312,500	400,033
Micronesia	**538,800**	**607,700**	**676,300**
FSM	102,400	100,000	105,300
Guam	187,100	224,200	250,400
Kiribati	100,800	119,900	144,600
Marshall Islands	54,400	59,500	62,700
Nauru	10,000	12,000	14,400
CNMI	63,100	70,300	76,200
Palau	20,500	21,800	22,700
Polynesia	**663,800**	**710,800**	**780,800**
American Samoa	65,900	74,600	87,300
Cook Islands	15,700	16,400	16,900
French Polynesia	268,800	297,600	330,800
Niue	1500	1200	1200
Pitcairn Islands	*	*	*
Samoa	183,100	188,400	202,000
Tokelau	1200	1200	1200
Tonga	103,400	106,500	115,000
Tuvalu	11,100	11,800	12,800
Wallis and Futuna	13,100	13,100	13,600
Total	**9,856,300**	**11,783,500**	**14,949,471**

* Population for Pitcairn Islands not estimated (currently 66).

Priority adaptations to climate change for Pacific fisheries and aquaculture

Reducing risks and capitalizing on opportunities

FAO/Secretariat of the Pacific Community
5–8 June 2012
Noumea, New Caledonia

These are the Proceedings from the Workshop "Priority adaptations to climate change for Pacific fisheries and aquaculture: reducing risks and capitalizing on opportunities" held in Noumea, New Caledonia, from 5 to 8 June 2012 and organized by the Secretariat of the Pacific Community in collaboration with the FAO Fisheries and Aquaculture Department. The meeting brought together representatives from fisheries, climate change and disaster risk management from across the Pacific island countries and territories (PICTs) to discuss the implications of climate change for Pacific fisheries and aquaculture, and priority adaptations for economic development and government revenue, food security and sustainable livelihoods for Melanesian, Micronesian and Polynesian nations. The adaptations identified reflect the different fisheries participation rates and importance of fish to economic development and as a source of local food and income in these different regions. Ultimately, the Workshop discussions recommended immediate action by all PICTs to manage fisheries resources sustainably now and into the future, and establish systems to minimize impacts of various drivers facing the sector now and from future climate change, and to capitalize on opportunities. Cooperation between PICTs and partnerships between governments, regional and international organizations and communities were highlighted as important ways to implement effective adaptation.

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