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Climate Change, Fisheries and Aquaculture in the Pacific

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IRD Institut de recherche pour le développement · DLR · SPC Secretariat of the Pacific Community · ministry of science + innovation TE PŪNAHA HIRINGA WHAKAEA · APRE Agenzia per la Promozione della Ricerca Europea · MCST · ANU The Australian National University · USP The University of the South Pacific · euro Research Support

Key Messages

Fisheries and aquaculture are of major importance to Pacific Island countries and territories for economic development, government revenue, food security and livelihoods. These benefits are at risk from many factors affecting the sector. Climate change is one of these factors, and is expected to become a stronger 'driver' of fisheries and aquaculture production over time.

The vulnerability of the fisheries and aquaculture sector in the Pacific to climate change has been assessed recently by the Secretariat of the Pacific Community. The key findings indicated that there are likely to be losers and winners.

Decreases in production of coastal capture fisheries and coastal aquaculture production are expected to occur as a result of (1) the direct effects of climate change (e.g. higher water temperatures and lower pH) on the reproduction, recruitment, growth and survival of key species; and (2) the indirect effects of degradation of coastal habitats (coral reefs, mangroves and seagrasses) as a result of increased temperatures, rainfall and ocean acidification, and possibly more intense cyclones.

Increases in tuna catches are expected across the region over the next 2-3 decades, but mainly in the east (with decreases eventually occurring in the west). Production of freshwater fisheries and freshwater pond aquaculture is likely to be favoured by higher rainfall and warmer water temperatures.

'No regrets' adaptations are available to minimise the risks of climate change to the sector and maximise the opportunities. These adaptations address the effects of drivers like population growth and urbanisation in the shorter term and climate change in the longer term.

Investments are needed in:

- Research to fill the gaps in knowledge required to further reduce vulnerability of economies and communities to alterations in production of oceanic, coastal and freshwater fisheries and aquaculture caused by climate change;
- Developments to launch the 'no regrets' adaptations to reduce the threats and capitalise on the opportunities; and
- Innovations to monitor the status of resources, evaluate the success of adaptations, engage coastal and inland communities in developing and applying practical adaptations, and facilitate communication among all stakeholders to improve the uptake of these adaptations.

For maintaining the important contributions of tuna to economic growth, key investments in research, development and innovation include:

- Strengthening stock assessments for tuna to allow management agencies to maintain stocks at levels where the expected opportunities resulting from climate change can be harnessed;
- Improving the models for assessing the combined effects of climate change and fishing on tuna catches, including long-term observations of variation in the food webs that support tuna to inform and verify these models; and
- Development of better systems for collecting and transmitting data on (i) species composition and length frequency of tuna, and (ii) features of the ocean of importance to modeling tuna (e.g. water temperature profiles and acoustic data for tuna prey), onboard industrial fishing vessels.

For food security, the key investments centre around:

- Minimising the gap emerging between the fish needed by coastal and urban communities and the best possible sustainable harvests from coastal fisheries – this involves better use of catchments to maintain vegetation to safeguard the coral reefs, mangroves and seagrasses underpinning coastal fisheries production from sediments and nutrients, and preventing over-exploitation of coastal fish stocks;
- Filling the gap by (i) improving access to the region's rich tuna resources for national food security through innovations to make tuna

from industrial catches more available to urban communities and installing anchored fish aggregating devices to help coastal communities catch more tuna; (ii) developing fisheries for small pelagic fish species (e.g. mackerel and pilchards); and (iii) expanding freshwater pond aquaculture in locations where communities are likely to have poor access to tuna, e.g. inland Papua New Guinea; and

- Research and innovations to maintain the appeal of coastal areas for tourism to increase the disposable income of coastal communities.

Partnerships already exist to do the necessary research, development and innovation on behalf of Pacific Island countries and territories but additional resources and member institutions are needed to strengthen these partnerships and increase the participation and contributions of the target communities.

The proposed investments will help make adaptive responses by policy makers, managers, fishing communities and enterprises faster, less expensive and more flexible. In particular, these investments should also help ensure that:

- Well-managed tuna resources continue to make major contributions to Pacific economies;
- Threats to vital coastal fish habitats and stocks are reduced;
- Practical 'no regrets' adaptations for economies and communities are launched; and
- The fisheries and aquaculture sector builds resilience not only to climate change but to a broad range of other drivers, especially the effects of rapid population growth and urbanisation.

Abstract

Fisheries and aquaculture make outstanding contributions to the food security and livelihood opportunities in Pacific Island countries and territories (PICTs). To assist PICTs to understand how climate change could affect these benefits, the Secretariat of the Pacific Community recently assessed the vulnerability of tropical Pacific fisheries and aquaculture to climate change. The results of the assessment indicate that there will be winners and losers. Tuna catches are eventually expected to be higher around PICTs in the eastern Pacific but lower in the west. Harvests from coastal fisheries and coastal aquaculture (mariculture) are projected to decrease across the region but greater yields are likely from freshwater fisheries and pond aquaculture.

There are 'no regrets' adaptations that can address the effects of drivers like population growth in the shorter term and climate change in the longer term. These adaptations, and the policies recommended to support them, are designed to reduce the risks posed by climate change and capitalize on the opportunities. Investments are needed in research to launch the recommended adaptations, fill gaps in knowledge and fund the innovations needed to engage governments and communities in developing and applying practical adaptations, facilitating communication among all stakeholders to improve the uptake of these adaptations, monitor the status of resources and evaluate the success of adaptations.

Effective partnerships already exist between the Council of Regional Organisations of the Pacific and European research agencies to fill some of the gaps in knowledge and develop the innovations needed to effectively implement priority adaptations and policies. However, a broader network of European and Pacific research partners is needed to do the physical, biological and social science required to strengthen resilience of the fisheries and aquaculture sector to climate change.

Significance of the Sector

Pacific Island countries and territories (PICTs) face considerable challenges in implementing their shared vision for a secure and prosperous region in the face of population growth and urbanisation (particularly in Melanesia), which create the need for more jobs, puts food security at risk and increases pressure on fragile habitats; unstable financial markets; escalating food prices; and changing terms of trade. Population growth and urbanisation are particularly powerful drivers of development outcomes. The total population of all PICTs combined was estimated to be 9.9 million in 2010, and is projected to rise by ~ 50% to ~ 15 million in 2035 and 18 million by 2050[1]. Most of the region's population is concentrated in Papua New Guinea (PNG) and elsewhere in Melanesia, where rapid urbanisation is also underway caused by migration from outer islands and rural areas to the main population centres. In PNG, urban populations are predicted to increase by 180% by 2035, compared to a total population increase of 60%. In contrast, some of the smaller PICTs (Cook Islands, Nauru, Niue, Pitcairn Islands, Tokelau, Tuvalu) have experienced a population decline in recent years due to emigration. Overall, however, the rapidly growing population of the region means that new approaches will be needed to achieve the collective goals of economic, human and social development.

The vital contributions of sustainable fisheries and aquaculture to the development goals of the Pacific Islands region cannot be overstated. Nowhere else in the world do so many countries and territories depend as heavily on the benefits derived from catching or growing fish and shellfish. Licence fees from distant water fishing nations (DWFNs) contribute substantially to the national economies of seven PICTs (Gillett 2009). In the case of Kiribati, Nauru and Tuvalu, these contributions average about 40%, 20% and 10% of annual government revenue respectively. Domestic fishing fleets and local fish processing operations also provide significant further benefits and account for around 20% of gross domestic product (GDP) in Marshall Islands and American Samoa.

Fish is also a cornerstone of food security. In more than half of all 22 PICTs, fish consumption is at least 2–4 times greater than the global average. In most rural areas, 60–90% of this fish comes from subsistence fishing activities and fish often makes up 50–90% of dietary animal protein (Bell et al. 2009). Limits to the production of fish from coastal habitats, the large quantities of fish needed for food security and the great dependence on subsistence fishing means that there is little scope for export of coastal fish from PICTs.

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 (Gillett 2009). Surveys in 17 PICTs show that an average of 47% of households in coastal fishing communities earn either their first or second income from fishing or selling fish for local consumption (SPC 2008a). Pearl farming in some remote atolls in Polynesia is an important source of employment and provides one of the few main exports by the sector other than tuna and sea cucumbers. Freshwater pond aquaculture is now expanding in inland PNG, where >10,000 households are engaged in small-scale freshwater fish farming (Ponia 2010, Pickering et al. 2011).

The benefits of the region's fisheries are not limited to PICTs, however, The rich tuna resources of the tropical Pacific are in demand worldwide, including Europe, where they provide jobs in the processing sector and an important supply of fish for consumers. The interim economic partnership agreement (IEPA) between the EU and PNG has improved the access of tuna from the region to markets in Europe. The EU is also assisting other PICTs to conform to the regulations on illegal, unreported and unregulated (IUU) fishing and food safety requirements so that catches from their exclusive economic zones can be processed in PNG under the global sourcing provisions of the IEPA to meet the EU requirements.

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

National and Regional Policy Frameworks

Implementing practical plans to maximise the sustainable economic and social benefits from fisheries and aquaculture in the region is an integral part of the Pacific Plan[1]. The importance of such action was reinforced by Pacific Island Leaders in their Vava'u Declaration[2]. The necessary plans centre around: 1) optimising the economic benefits from tuna; 2) providing access to the fish needed for the food security of rapidly growing populations; and 3) identifying how many livelihoods can be sustained from oceanic and coastal fisheries, and aquaculture (SPC 2007a, Gillett and Cartwright 2010).

PICTs are acutely aware that their aspirations to maximise economic benefits from tuna are tied to sound co-operative management of trans-boundary stocks (Lehodey et al. 2011). Co-operative management was launched in 1979, with the formation of the Pacific Islands Forum Fisheries Agency (FFA)[3] to help national fisheries departments manage fishing effort by DWFNs and domestic fleets, within their exclusive economic zones (EEZs). Key management measures and treaties developed and implemented by FFA on behalf of its members are provided in Bell et al. (2011).

The trans-boundary nature of the region's oceanic fisheries resources, which also allows them to be captured on the high seas, calls for a broader approach. In response to the need to manage tuna stocks across the entire Western and Central Pacific Ocean (WCPO), the Convention for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean was declared in 2004. The Western and Central Pacific Fisheries Commission (WCPFC) was established to administer this convention in 2005[4]. 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.

1 www.forumsec.org/resources/uploads/attachments/documents/Pacific_Plan_Nov_2007_version.pdf.

2 www.forumsec.org.fj/resources/uploads/attachments/documents/THE%20Vava'u%20declaration.pdf.

3 www.ffa.int. The Members of FFA are: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, together with Australia and New Zealand.

4 www.wcpfc.int. Members of WCPFC and participating territories include Australia, Canada, China, Cook Islands, European Union, Federated States of Micronesia, Fiji, France, Japan, Kiribati, Korea, Marshall Islands, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Philippines, Samoa, Solomon Islands, Taiwan/ROC, Tonga, Tuvalu, United States of America and Vanuatu.

Much of the tuna catch from the WCPO comes from the countries that are Parties to the Nauru Agreement[5] (PNA); approximately 40% of the world's canning tuna is caught in their EEZs. In 2010, PNA members established an independent secretariat to explore collective ways to increase the contributions of the tuna resources within their EEZs to their economic development. In a similar move, the Polynesian countries have launched the Te Vaka Moana Arrangement (TVMA) to optimise the benefits from longline fishing for tuna in their EEZs. FFA, WCPFC, PNA and TVMA co-operate to maintain tuna stocks within the WCPO at levels that ensure conservation of the stocks and delivery of sustainable economic benefits.

The framework for managing coastal and freshwater fisheries is based on the well-recognised need for an ecosystem approach to fisheries management (FAO 2003), and primary fisheries management (Cochrane et al. 2010). These two principles are being merged into a 'community-based ecosystem approach to fisheries management' (CEAFM) for the region (SPC 2010). This merger requires underpinning legislation and support for communities and national agencies from regional fisheries and environmental organisations and NGOs.

To promote aquaculture, the regional Aquaculture Action Plan (SPC 2007b) and national aquaculture plans encourage investment, specify licensing arrangements, guarantee access to suitable sites, set quality standards for products, support pilot commercial projects and implement global standards for aquatic animal health and biosecurity (OIE 2010).

'The Future of Pacific Island Fisheries' study (Gillett and Cartwright 2010) maps out the management measures needed to achieve the potential economic, food security and livelihoods benefits from tuna, coastal and freshwater fisheries and aquaculture. It also identifies plausible scenarios that could result in loss of potential benefits. Achieving good outcomes will depend on the collective ability of PICTs to respond to the various drivers likely to affect the sector.

5 www.pnatuna.com. Members are Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands and Tuvalu.

Climate change is one of these drivers (Brander 2012). There are serious concerns that global warming and ocean acidification could affect the plans being made to optimise the social and economic benefits derived by PICTs from fisheries and aquaculture.

Status of Research on the Vulnerability of the Sector to Climate Change

To assist PICTs to understand the risks posed by climate change to their plans to optimise the economic and social benefits from fisheries and aquaculture, SPC has recently completed a comprehensive vulnerability assessment for the sector (Bell et al. 2011; www.spc.int/climate-change/fisheries/assessment/).

The assessment involved contributions from almost 90 scientists and fisheries and aquaculture specialists from 36 institutions. This team produced comprehensive analyses in six broad areas.

1. Observed and projected changes to atmospheric (surface) climate.
2. Observed and projected changes to the tropical Pacific Ocean.
3. Effects of projected changes in surface climate and the ocean on the ecosystems that support fisheries resources (food webs for tuna, the coral reefs, mangroves and seagrasses that sustain coastal fisheries, and the habitats critical to freshwater and estuarine fisheries).
4. Direct effects of projected changes to surface climate and the ocean, and the indirect effects of projected changes to ecosystems, on the abundance and distribution of the fish and shellfish species supporting oceanic fisheries, coastal fisheries, freshwater fisheries and aquaculture.
5. Implications of projected changes to the nature and productivity of fisheries and aquaculture for regional plans to optimise the economic, food security and livelihoods benefits of the sector.
6. Adaptations and policies to help economies and communities maintain (or increase) the benefits of fisheries and aquaculture in the face of climate change.

Main Results of the Vulnerability Assessment

Projected changes to surface climate

Surface air temperatures in the tropical Pacific are projected to continue their observed warming trend (Lough et al. 2011). 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 under the IPCC A2 high emissions scenario. There is more uncertainty about how rainfall patterns will change across the tropical Pacific. However, it seems likely that rainfall will increase by 5-20% in 2035 and by 10-20% between 2050 and 2100 in the convergence zones near the equator. Rainfall is expected to decrease by 5-20% in the subtropics. Warming oceans are expected to intensify the hydrological cycle, which is likely to lead to more extreme rainfall events and more intense droughts (Lough et al. 2011).

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. 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.

Projected changes to the ocean

The currents in the tropical Pacific Ocean are expected to change due to global warming (Ganachaud et al. 2011). In particular, the South Equatorial Current near the equator is projected to decrease by 3-5% by 2035, 9% by 2050 and 18% by 2100 under the A2 scenario The Equatorial Undercurrent is expected to move progressively upward by 20 m by 2100 and increase by 6% over the course of the century. Eddy activity is likely to increase or decrease in association with projected changes in current strength (Ganachaud et al. 2011).

Sea surface temperature (SST) is expected to continue rising substantially, increasing 0.7°C by 2035, 1.4°C by 2050 and 2.5°C by 2100 under the A2 scenario (Ganachaud et al. 2011). The salinity of the tropical western Pacific Ocean is projected to decrease in line with the intensified hydrological cycle. The salinity front associated with the Warm Pool is likely to extend further east by ~ 2000 km, while the 29°C isotherm is expected to move further east at the equator.

The stratification of the ocean is expected to increase by ~ 10% by 2035, 10-20% by 2050, and 20-30% by 2100, with the greatest changes in the Warm Pool (Ganachaud et al. 2011). Increased stratification will limit the supply of nutrients to the photic zone and reduce primary production, except in the equatorial upwelling.

The increasing temperature and stratification of the ocean at higher latitudes are projected to lead to decreased transfer of oxygen (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.

Increases in atmospheric CO_2 are projected to reduce the pH of the ocean by 0.3 units under the A2 scenario by 2100. At such rates of change, aragonite saturation levels in the tropical Pacific Ocean are expected to fall substantially across the region, eventually to levels that will affect the growth of coral reefs (Hoegh-Guldberg et al. 2011).

The rate of sea-level rise is expected to accelerate and projections from IPCC-AR4 that sea level will rise by up to 51 cm under A2 by 2100 are now considered to be conservative because they do not include the effects of increased flow from land ice. 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 rise by as much as 70-100 cm by 2050 and 90-140 cm by 2100 (Ganachaud et al. 2011).

Projected effects on the ecosystems supporting fish

The area and productivity of the two main provinces supporting tuna in the tropical Pacific, the Warm Pool in the west and the equatorial upwelling in the centre and east of the region (Figure 1), are projected to change (Le Borgne et al. 2011). By 2050, the area of the equatorial upwelling is expected to decrease by ~30%, whereas the Warm Pool is likely to increase by 25%. The convergence of the Warm Pool and the equatorial upwelling is expected to move to the east. This convergence zone is a prime feeding area for tuna (Lehodey et al. 2011) and its position can shift by up to 3-4000 km due to strong El Niño and Niña events. Similar shifts in the position of the convergence may occur due to climate change, although further research is needed to confirm this.

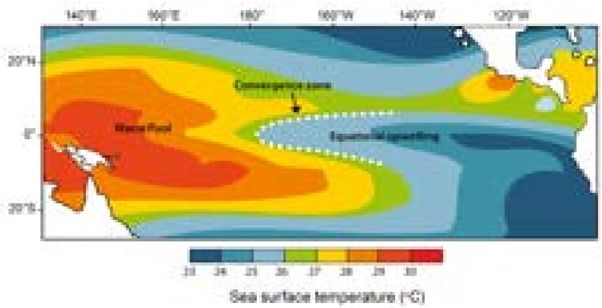

Figure 1. Typical locations of the Warm Pool in the western Pacific and its convergence with the nutrient-rich waters of the equatorial upwelling under La Niña conditions (source: Bell et al. 2011, Chapter 1).

The habitats that support coastal fisheries are expected to be degraded severely by climate change (Table 1). Increasing SSTs, ocean acidification and increased runoff from high islands due to greater rainfall are expected to result in conditions that make it increasingly difficult for corals to grow (Hoegh-Guldberg et al. 2011). The processes that erode coral reefs are therefore expected to exceed the rates of calcification, causing large losses of hard substrata derived from corals and coralline algae. Even with good local management (e.g. effective management of catchments to minimise the transfer of sediments and nutrients to coastal waters), there is expected to be a 90% loss of live coral cover by 2100 under the A2 emissions scenario (Table 1). Large losses of mangroves, mainly as a result of sea-level rise, and seagrasses due to increased temperatures and increased runoff, are also expected (Table 1) (Waycott et al. 2011).

Modest increases (up to 10% by 2035 and 2050) are expected in the extent of floodplains and other freshwater habitats due to increased river flows stemming from higher rainfall (Gehrke et al. 2011a). These changes are expected to occur mainly in PNG, but also in Fiji and Solomon Islands to some extent.

Projected effects on fish stocks and aquaculture

The projected changes to the tropical Pacific Ocean are expected to favour the abundant skipjack tuna across the region in the shorter term (Lehodey et al. 2011). Increases in the catch of this species are projected in both the west and the east by 2035 (Table 2). However, as the distribution of this impor-

Table 1. Projected changes to coastal fish habitat in the tropical Pacific under a high (IPCC A2) emissions scenario in 2035, 2050 and 2100, relative to 1980–1999 (source: Hoegh-Guldberg et al. 2011; Waycott et al. 2011)

Habitat	Type of change	Year	Change (%)
Coral reef	Live coral cover	2035	-25 to -65*
		2050[a]	-50 to -70*
		2100	> -90*
Mangrove	Area	2035	-10 to -30
		2050[a]	-50 to -70
		2100	-60 to -80
Seagrass	Area	2035	-5 to -20
		2050[a]	-5 to -35
		2100	-10 to -50

[a] Based on projections for IPCC B1 emissions scenario in 2100
* Based on strong management of coral reefs to minimize the effects of local stressors

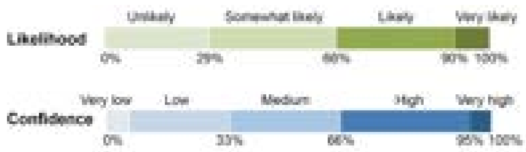

Table 2. Projected percentage changes in average catches of skipjack and bigeye tuna for the eastern (15°N–20°S; 130°–170°E) and western Pacific (5°N–15°S; 170°E and 150°W) in 2035, 2050 and 2100 under a high (IPCC A2) emissions scenario relative to 1980–2000 (source: Lehodey et al. 2011)

Tuna species	West			East		
	2035	2050	2100	2035	2050	2100
Skipjack	+10	0	-20	+30 to 35	+40 to 45	+25 to 30
Bigeye	0 to -5	-10 to -15	-30 to -35	0 to +5	0 to +5	-15 to -20

tant species shifts progressively to the east with the changing climate (Figure 2), catches are expected to remain higher in the east but decrease in the west (Table 2). By 2100 under the A2 emissions scenario, preliminary modelling indicates that there could be a net decrease of ~10% in tuna catches across the entire region compared to 1980-2000 due to climate change alone (Lehodey et al. 2011).

Production of the bottom-dwelling fish associated with coral reefs and other coastal habitats is expected to decline progressively across the region. These changes are likely to result from both the direct effects of climate change (e.g. the influence of higher water temperatures on the spawning success and distribution of key species), and the indirect effects of degradation to the habitats that support coastal fisheries (Table 1) (Pratchett et al. 2011). Decreases in the production of coastal bottom-dwelling fish, which are so important to food security of the region, are expected to range from 2-5% by 2035, 20% by 2050 and 20-50% by 2100 under the A2 emissions scenario.

The projected greater availability of freshwater fish habitats as rainfall increases is estimated to result in increases in freshwater fish production of up to 2.5% by 2035, 7.5% by 2050 and 12.5% by 2100 under the A2 emissions scenario (Gehrke et al. 2011b).

The higher rainfall and warmer air temperatures expected to occur in the tropics should improve the conditions for freshwater pond aquaculture.

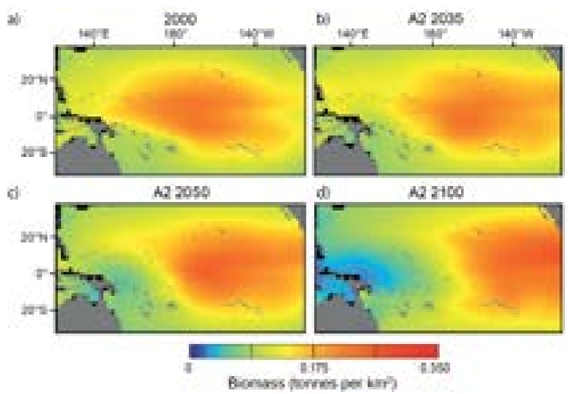

Figure 2. Projected estimates of total biomass (tonnes per km^2) of skipjack tuna from the SEAPODYM model based on average (1980–2000) fishing effort in (a) 2000, (b) 2035, (c) 2050 and (d) 2100. Projections are for a high (IPPC A2) emissions scenario (source: Lehodey et al. 2011)

Projected increases in SST, rainfall, sea level, ocean acidification and the intensity of cyclones are likely to reduce the suitability of coastal habitats for the range of commodities presently grown there.

Implications for Economic Development, Food Security and Livelihoods

Economic development

The projected changes to the catches of tuna across the region are expected to have implications for government revenue and gross domestic product (GDP) in PICTs where tuna are caught and/or processed. For PICTs in the central and eastern Pacific, where access fees from DWFNs already provide a large proportion of government revenue (Kiribati, Tokelau and Tuvalu), there could be substantial potential to negotiate for increased revenue between 2035 and 2050, with opportunities diminishing by 2100 (Bell et al. 2011, Chapter 12). Contributions of tuna to GDP could also increase in Marshall Islands until 2100 as a result of the greater catches by national vessels. Similarly, canning operations in American Samoa are likely to have the potential to benefit from the more eastern distribution of tuna until 2050.

The projected reduction in tuna catches from the exclusive economic zones (EEZs) of Papua New Guinea (PNG) and Solomon Islands in 2050 and 2100 (Lehodey et al. 2011) could affect the existing and proposed canneries there unless arrangements can be made to maintain the supplies of fish needed for processing operations. In the event that such measures are not successful, the projected reductions in tuna catch from the EEZs of PNG and Solomon Islands could affect the profitability of canneries and the opportunities for employment. Overall, however, the potential impacts on economic development in PNG and Solomon Islands would be relatively limited because present-day catches are surplus to national canning needs and the fisheries sector makes a minor contribution to GDP in these relatively large economies.

Food security

The projected changes to the supply of bottom-dwelling fish associated with coral reefs are expected to have effects on food security because so many people in the Pacific depend heavily on these coastal fisheries resources for dietary protein (SPC 2008b, Bell et al. 2009). However, the effects of climate change on this fish production are expected to be relatively minor compared to those of population growth. The rapid increase in population size in many PICTs means that the limited amount of fish that can be harvested from coral reefs will provide less fish per capita over time and the fish available from reefs will fall increasingly short of the 35 kg of fish per person per year recommended for good nutrition (Figure 3). The existing trend for low quality imported processed foods to replace fish in the diet can be expected to exacerbate the growing incidence of non communicable diseases in the region (SPC 2008c).

For the PICTs in this category (Fiji, Guam, Nauru, Commonwealth of the Northern Mariana Islands, PNG, Samoa, Solomon Islands and Vanuatu), plans are needed to provide access to the fish required for food security in the face of growing population and climate change. These plans involve (1) improving the management of coastal habitats and fish stocks to reduce the gap to be filled between the fish needed for food security and sustainable coastal fish harvests; (2) assessing how best to fill the gap with tuna; (3) promoting the 'vehicles' needed to deliver the fish required; and (4) allocating the appropriate proportion of the tuna catch to meet the needs for food security (Bell et al. 2009; Bell et al. 2011, Chapters 12 and 13).

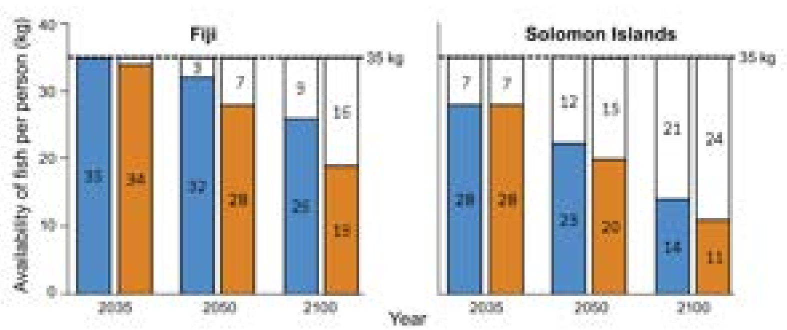

Figure 3. Relative effects of population growth and the A2 emissions scenario on the gap between recommended annual fish consumption of 35 kg per person, and the estimated annual supply of fish from coastal (reef-associated) and freshwater fisheries in 2035, 2050 and 2100 for Fiji and Solomon Islands; ■ = availability of fish per person due to the effects of population growth alone; ■ = availability of fish per person remaining after the combined effects of population growth and climate change (source: Bell et al. 2011, Chapter 12)

Livelihoods

Apart from the need to make arrangements to ensure that tuna can be supplied cost-effectively to the existing and proposed canneries and loining enterprises in the region, the implications of the projected changes in production from fisheries and aquaculture for livelihoods are that some existing jobs may need to be switched from one resource to another.

Within the coastal fisheries sector, the effort of small-scale fishers will need to be increasingly transferred from bottom-dwelling fish associated with coral reefs to tuna and other large oceanic fish when they come close to the shore. This will require an increased use of nearshore fish attracting devices (FADs) (SPC 2012) (Figure 4). Transferring effort to oceanic fish species is not only expected to help maintain the livelihoods of fishers as the projected declines in coastal fisheries occur (Pratchett et al. 2011), it should also create additional job opportunities in all PICTs over the next 2-3 decades, and over the longer term in PICTs in the central and eastern Pacific, because of the likely increases in the abundance of tuna (Table 2).

For aquaculture, much of the potential for growth in jobs is expected to be based on farming freshwater fish in ponds. Such enterprises are likely to be enhanced by the projected increases in rainfall and temperature (Pickering et al. 2011). However, governments will need to organise training programmes and provide incentives for the private sector to invest in the hatcheries and other infrastructure required to capitalise on these opportunities.

The projected degradation of coral reefs is also likely to have implications for the tourism sector, which needs to be developed in Melanesia to provide job opportunities for rapidly growing population. A key challenge will be finding ways to maintain the attractiveness of coral reefs as the frequency of coral bleaching events increases and net erosion of reefs occurs due to the effects of ocean acidification (Hoegh-Guldberg et al. 2100).

Proposed Adaptations and Supporting Policies

A selection of proposed adaptations and supporting policies to reduce the risks to the benefits of fisheries and aquaculture for economic development, food security and livelihoods posed by climate change, and to capitalise on the opportunities, is given below. A full list is given in Bell et al. (2011, Chapter 13). In most cases, the proposed interventions are 'no regrets' (win-win) adaptations designed to address strong drivers like population growth and urbanisation in the short term and climate change in the long term (Grafton 2010). The remainder are 'lose-win' adaptations, which involve costs and sacrifices now (e.g. decisions to forego fish harvests now to help restore fish stocks to more robust levels) in order to build the resilience of resources to climate change.

Economic Development

Adaptations

The adaptations required to maximise the benefits from tuna fisheries for PICTs involve (1) development of flexible management measures to allow fishing effort to shift east, while ensuring that large quantities of tuna can still be channelled through the established and proposed canneries in the west; and (2) optimising the productivity of tuna resources across the region.

Full implementation of the vessel day scheme (VDS): The 'cap and trade' provisions of the 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: The global sourcing provisions of an EPA assist countries processing tuna to obtain and export fish at competitive prices. Developing and maintaining a long-term EPA will help ensure that these countries have continued supplies of fish as tuna are redistributed further east.

Diversify sources of fish for canneries: Other adaptations to help countries 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 management measures for bigeye tuna: Preventing the overfishing of bigeye tuna in the WCPO should help rebuild the stock and make this valuable species more resilient to climate change.

Energy efficiency programmes for industrial fleets: 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: Minimising 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.

Supporting policies

1. Promote transparent access agreements between Pacific Island economies and DWFNs so that allocations under the VDS (and other fishing effort schemes) are understood by all stakeholders; and strengthen national capacity to implement these schemes.

2. Adjust national tuna management plans and marketing strategies to provide more flexible arrangements to sell tuna, or acquire tuna needed for local processing operations.

3. Include the implications of climate change in the future management objectives of the WCPFC.

4. Require all industrial tuna vessels to provide operational-level catch and effort data to improve the models for estimating the redistribution of tuna stocks.

5. Apply national management measures to address the implications of climate change for subregional concentrations of tuna in national archipelagic waters beyond the mandate of WCPFC.

6. Develop further measures to mitigate the capture of bigeye tuna by purse-seine.

7. Use regional trade and preferential access agreements to market environmentally-friendly tuna products, and develop distribution channels that minimise CO_2 emissions.

Food Security

Adaptations

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

Manage and restore vegetation in catchments: Increasing the vegetation in catchments will help reduce the transfer of sediments and nutrients to rivers and coasts after heavy rain and help prevent damage to the coral reefs, mangroves and seagrasses supporting coastal fisheries.

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

Provide for landward migration of coastal fish habitats: 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 level rises.

Sustain production of bottom-dwelling fish: Maintaining the replenishment potential of stocks will help reduce the gap between coastal fisheries production and the fish needed by rapidly growing populations.

Diversify catches of bottom-dwelling fish: 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 food security: Installing anchored fish aggregating devices (FADs) (Figure 4) to attract tuna close to the coast will provide subsistence and small-scale commercial fishers with better access to fish as human populations increase and coastal bottom-dwelling fish decline. 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.

Develop coastal fisheries for small pelagic species: Increasing the catch of mackerel, anchovies, pilchards, sardines, scads and fusiliers will improve access to fish for food security and livelihoods.

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

Improve post-harvest methods: 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.

Supporting policies

1. Strengthen governance for the major reforms in planning needed to achieve sustainable use of all coastal fish habitats and integrated coastal zone management by: (i) building the capacity of management agencies to understand the threats posed by climate change; (ii) empowering communities to manage fish habitats; and (iii) changing agriculture, forestry and mining practices to prevent sedimentation and pollution.

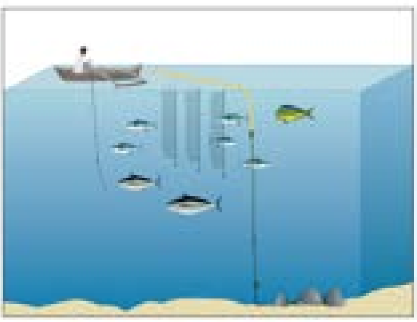

Figure 4. Anchored fish aggregating device (FAD) suitable for placing in coastal waters to increase access to tuna (source: Bell et al. 2011, Chapter 13)

2. Minimise barriers to landward migration of coastal habitats during development of strategies to assist other sectors respond to climate change.

3. Promote mangrove replanting programmes in suitable areas to meet the twin objectives of enhancing habitat for coastal fisheries and capturing carbon.

4. Apply CEAFM and 'primary fisheries management' to stocks of coastal fish and shellfish to maintain their potential for replenishment.

5. Increase access to tuna for the food security of coastal communities where required by reducing national allocations to industrial fleets.

6. Include anchored inshore FADs as part of the national infrastructure for food security, and making provision for regular maintenance and replacement of FADs.

7. Provide training and technical support for coastal fishing communities to fish around inshore FADs, and to catch small pelagic fish.

8. Promote 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 limit Nile tilapia farming to catchments where the Mozambique tilapia is already established to reduce any possible effects on freshwater biodiversity.

Livelihoods

Adaptations

Rebuild populations of sea cucumbers and trochus: Restoring the densities of these valuable species to levels above the thresholds required for regular replenishment will result in some loss of income in the short term (which needs to be addressed by targeted programmes), but set the stage for greater benefits through increased exports in the future.

Develop coral reef ecotourism ventures: Reducing the pressure on fisheries resources by providing viable alternative sources of income for local communities in the tourism sector is expected to make fisheries for bottom-dwelling fish and shellfish less vulnerable to climate change. However, strategies will be needed to maintain the attractiveness of coral reefs for tourists in the face of increasingly hostile conditions for the growth of coral.

Diversify production of coastal aquaculture commodities: Assessing the potential to grow 'new' commodities favoured by projected environmental conditions may create new livelihoods.

Modify locations and infrastructure for coastal aquaculture: Timely alterations to the design and position of facilities can help reduce the expected negative effects of sea-level rise, ocean acidification and higher water temperatures on coastal aquaculture activities.

Supporting policies

1. Facilitate training needed to operate profitable businesses based on small-scale coastal fisheries and aquaculture activities for rural communities and promote innovation networks to increase the uptake of efficient practices.

2. Promote private sector investment in coastal tourism designed to accommodate climate change, particularly the projected changes in sea level, storm surge and changes to coral reefs and other coastal habitats.

3. Strengthen national and regional capacity to adopt and implement aquatic animal health and biosecurity measures, including development of a regional aquatic biosecurity framework and international protocols for monitoring, detecting and reporting aquatic animal diseases to prevent introduction of new pathogens.

Research, Development and Innovation Areas Needing Action in the Pacific

Much uncertainty still surrounds the vulnerability assessment for the fisheries and aquaculture sector. 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 (not the subject of this Policy Brief) uncertainty can be reduced by filling gaps in the knowledge of the ecology of fish habitats and the biology of harvested fish and shellfish. The research and development activities needed to fill these gaps are summarised below (see Bell et al. 2011, Chapter 13 for full details).

The list of research to be completed is extensive and priorities will differ among PICTs. 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. Similar arguments can also be made for the research recommended to improve management of freshwater fisheries and pond aquaculture. Such research promises to improve the food security of the large and rapidly growing inland populations of PNG, where the majority of the people in the region live.

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. Except for the Hawaii Ocean Time-Series station, no long-term observations of nutrients, oxygen or the abundances of phytoplankton, zooplankton and micronekton exist in the region. More long-term time-series data are a priority. Better biogeochemical models will also pave the way for improved application of ecosystem models (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 parameterise 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:

- What is the effect 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?
- Will synergies between projected increases in SST, ocean acidification and nutrient loads, and possibly more powerful waves from stronger tropical cyclones, damage coral reefs more severely?
- What are the likely consequences for coral reefs of a very rapid rise in sea level?
- Which coral reef habitats are 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 and estuaries

Little is known about freshwater rivers and estuaries. Ecosystem models for representative river types need to be developed and validated so that managers do not have to rely on information from other parts of the world. Important first steps are to quantify and map the habitats created by rivers and estuaries, and to set benchmarks for identifying changes in habitat area and quality.

Fish Stocks and Aquaculture

Tuna

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

- Identify the likely effects of variation in temperature, dissolved oxygen and ocean acidification (and their interactions) 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 diversity, distribution and abundance of micronekton; diets of tuna; and the influence of nutrient-rich coastal waters as feeding areas for tuna (the archipelagic waters under the influence of increased runoff from the Sepik-Ramu river system in PNG are of particular interest).

In addition, finer spatial scale reporting of tuna catches is needed to parameterise the SEAPODYM model.

Coastal fisheries

A better understanding of the likely effects of climate change on the production of coastal fisheries depends on research to:

- Identify the responses of key fish and shellfish species to projected changes in quality (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 shellfish, and their links with coral reefs;
- Assess the sensitivity and adaptive capacity of key bottom-dwelling fish and shellfish to changes in SST and pH, including (1) the effects on early life history stages; and (2) the combined effects of these variables and their interactions with other 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 run-off around high islands on the productivity of small pelagic fish species.

Freshwater and estuarine fisheries

The priority here is to understand how the main species use various habitats at different stages of their life cycles, and their responses to changes in habitat availability and quality. It is also important to understand interactions among fish species (including with introduced and invasive species) and to determine whether such interactions are likely to be affected by the projected changes to water temperature and flow rates.

Aquaculture

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

- Identify areas most likely to be suitable for pond aquaculture in the future;
- Evaluate any potential impacts of Nile tilapia introduced for pond aquaculture on freshwater biodiversity; 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 coastal aquaculture 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 as SST increases.

Investments Required in Research, Development and Innovation

To maintain the important contributions of fisheries and aquaculture to PICTs, investments are needed not only to fill remaining gaps in knowledge about how economies and communities are likely to be exposed to projected changes in fish stocks and aquaculture production, but also in effective ways of engaging communities in assessing their vulnerability and assisting them to identify and implement the most practical adaptations. Much of the effort to date has gone into assessing the vulnerability of the fisheries and aquaculture sector at the national level. Investments are now needed to cascade the information to communities and to support them to (1) understand and apply the results, including evaluating any cultural or gender issues involved in adopting new methods; and (2) participate in improving and monitoring ongoing assessments of vulnerability. Frameworks for practical community-based approaches that should help integrate the analysis and governance required for effective management are provided by Cochrane et al. (2010), Miller et al. (2010) and Andrew and Evans (2011).

The key investments in the necessary research, development and innovation are outlined below. In the case of the investments to increase participation of communities in applying adaptations to address the various drivers affecting them now, and future climate change, it is assumed that the necessary governance and management to implement the steps needed to achieve desirable outcomes (Gillett and Cartwright 2010) will be in place.

Research to Fill the Gaps in Knowledge of Key Fisheries and Aquaculture Resources and Activities

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, parameterisation and verification of several biogeochemical models of the tropical Pacific Ocean, including collection of data on variability of nutrients, oxygen, pH, phytoplankton, zooplankton and micronekton throughout the water column; movements of tuna; diets of juvenile and adult tuna; and the responses of juvenile tuna to ocean acidification. This involves:
  - obtaining catch data from 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[1], 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[2];
  - 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, oxygen 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 (1) provide the finer-scale measurements (< 1 km) needed to manage individual reefs; and (2) 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 (1) the projected losses of mangroves blocked from migrating landward by infrastructure, and (2) the areas to be inundated that have potential for colonisation by mangroves and seagrasses;
- Assessing the likely effects of increases in SST and ocean acidification, and changes in the

1 www.argo.ucsd.edu.

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

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.

Freshwater and estuarine fisheries

- Flood modelling to identify likely changes to floodplain and estuarine fish habitats to allow national planners to provide for increased fisheries production when developing cross-sectoral strategies to adapt to projected increases in rainfall and sea-level rise;
- 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

- 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.

Developments to Launch Adaptations

Adaptations for economic development

- Establish competent authorities for fishery product food safety, and systems for demonstrating compliance with IUU fishing regulations in PICTs well placed to supply canneries in countries with EPAs with the EU;
- Energy audits and energy efficiency programmes for national industrial tuna fleets to assist them to cope with fluctuations in oil prices, and reduce the costs of fishing further afield as the distribution of tuna shifts to the east;
- Production chain accounting of all emissions from tuna fishing and canning/processing operation, and transport to markets, for carbon labelling of tuna products from the region.

Food security and livelihoods

- Integrated land use planning to: (1) stabilise 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 (stream-side) buffer zones; (2) protect coral reefs, mangroves and seagrasses from direct damage; (3) safeguard these fish habitats during the adaptation of other sectors to climate change; and (4) identify the modifications to infrastructure needed to allow mangroves and other coastal fish habitats to migrate landward as sea level rises;
- 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 FADs at these sites as part of the national infrastructure for food security;
- Practical business models for storing, processing and distributing small-sized tuna and bycatch landed at major ports to maintain the quality of these fish and provide increased access to fresh fish for rapidly growing urban populations;
- Analyses to identify the prime locations for peri-urban and rural pond aquaculture based on projected rainfall and temperature, and other demographic and natural resources layers available for GIS.

Establishing Effective, Ongoing Communications

- Assess how best to create and operate a transdiciplinary, multi-level communication network for stakeholders in the fisheries and aquaculture sector. This network should be interactive and inform stakeholders about the initiatives to assess the vulnerability of economies and communities, and the adaptations they can make to reduce the threats and capitalise on opportunities. This network should also be integrated with websites and portals operated by SPREP and SPC and their partners and include easy opportunities for coastal communities to exchange experiences and recognise remaining gaps in knowledge.
- Commission the production of appealing (state-of-the art) computer games customised for Pacific youth that will teach the key messages about vulnerability and the consequences of various adaptation decisions for all sectors

(including fisheries) in ways that will promote learning while having fun. Understanding the impacts of weather events and long-term climate change on activities such as fishing, agriculture, infrastructure essential for livelihoods, transport and migration should be key elements of such games.
- Analyze the effectiveness of the communication strategy and identify how best to respond to any shortcomings that may prevent co-ownership of adaptation initiatives by communities or hinder appropriate decision-making.

Participation, Capacity Building and Training

- Conduct a gender-sensitive evaluation of resource use and livelihood strategies by stakeholders in the fisheries and aquaculture sector, particularly coastal communities, to identify livelihood vulnerability and resilience with regards to projected climate change impacts. Develop appropriate ways to encourage stakeholders to participate in development of effective adaptation strategies to provide food security and livelihoods in the face of climate change.
- Apply such models for encouraging widespread participation of 'grass-roots' stakeholders in community-based adaptation responses, supported by easy-to-use decision support systems.
- Provide training in culturally sensitive communication for scientists and managers to facilitate effective adoption of participatory principles during joint adaptive response projects with communities.
- Promote capacity building and micro-credit schemes for community members to launch their preferred adaptation activities.

Innovations to Monitor Resources and Evaluate the Success of Adaptations

- Digital analysis of changes in species composition and size-frequency of tuna caught by purse-seine vessels, where data can preferably be processed by computers on board and transmitted to the Forum Fisheries Agency and Secretariat of the Pacific Community via the vessel monitoring system.
- Development of simple indicators to monitor catchment vegetation (e.g. satellite imagery), fish habitats and fish stocks, and to measure success of adaptations to build the resilience of these resources to climate change. Where practical, such indicators should be developed with communities and they should participate in the monitoring.
- Long-term monitoring programmes to detect changes in coastal fish habitats and stocks and determine which changes were due to climate change, as opposed to other drivers.
- Modifications to household and income expenditure surveys and censuses (and any other appropriate socio-economic tools) to measure the success of adaptations in maintaining the contributions of fisheries and aquaculture to food security and livelihoods.

Investment Strategies for Bridging Research, Development and Innovation Needs

Because many PICTs have limited national capacity, investments are needed to develop and support the technical and scientific teams required to assist PICTs with the necessary research, development and innovation.

The most practical strategy is to strengthen existing teams already working together to provide PICTs with the knowledge and innovations they need by (1) providing these teams with the financial resources required to complement their own contributions to complete priority tasks for PICTs; and (2) building broader partnerships where the existing teams do not have the necessary capacity.

Examples of research, development and innovation tasks/opportunities for the fisheries and aquaculture sector in the Pacific, and the teams need to provide effective solutions, are given below.

Task 1: Expansion of the SEAPODYM model used to estimate tuna catches under different climate change scenarios and development, parameterisation and verification of biogeochemical models needed by SEAPODYM (see p. 17). Partners: CLS (France), CSIRO (Australia), University of NSW (Australia), WMO, SPC, IRD (France), WCPFC, FFA, PNA, IATTC, IOC, NZAID (New Zealand) and Papua New Guinea.

Task 2: Digital analysis of changes in species composition and size-frequency of tuna caught by purse-seine vessels. Partners: SPC, FFA, WCPFC, PNA and UNIDO.

Task 3: Participatory programmes with local communities and other stakeholders to (1) identify the best sites for installing inshore FADs to increase access to tuna for subsistence and small-scale commercial fishers in rural areas, and (2) install FADs at these sites as part of the national infrastructure for food security. Partners: PICTs, SPC, IRD and IFREMER (France), WorldFish.

Task 4: Determining the likely effects of ocean acidification on growth and survival of juvenile and adult pearl oysters, and pearl quality. Partners: IRD and IFREMER (France), James Cook University (Australia).

Task 5: 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. Partners: IRD (France), CSIRO, University of Queensland and James Cook University (Australia), SPC, USP, PICTs.

Task 6: Establishing an effective communication network for all stakeholders in the fisheries and aquaculture sector. Partners: PICTs, SPREP, USP, SPC, One laptop per child initiative.

Task 7: Long-term monitoring programmes to detect changes in coastal fish habitats and stocks and determine which changes were due to climate change, as opposed to other drivers. Partners: SPC, IRD (France), USP, CSIRO and James Cook University (Australia), NOAA (USA), SPREP, PICTs.

Expected Impacts of Investments

The investments should assist governments and communities in the Pacific to meet the challenges involved in maintaining the important contributions of fisheries and aquaculture to economic development, food security and livelihoods in the face of climate change. These challenges are summarised below.

1. Improving the understanding of the likely effects of climate change on tuna stocks and creating flexible arrangements to (i) allow smaller PICTs in the central and eastern Pacific with a high dependence on tuna to maximise any opportunities for increased government revenue, and (ii) ensure continued supplies of tuna to the established and proposed processing facilities in the region as the distribution of tuna shifts to the east.

2. Working with governments and communities to reduce the effects of local stressors on coastal fish habitats through restoring and protecting catchment vegetation and preventing direct damage to coral reefs, mangroves, seagrasses from excess sediments, nutrients, pollution and poor management of waste.

3. Assisting communities to launch 'no regrets' adaptations to address the imminent reductions in the fish available from coastal fisheries per person due to population growth in ways that should be favoured by climate change, especially the development of inshore FADs and freshwater pond aquaculture.

4. Managing coastal aquaculture enterprises producing commodities for export and local markets to optimise employment opportunities in the face of increasingly adverse conditions due to climate change and ocean acidification.

Meeting these challenges will also address other pressures that face the sector, particularly the effects of rapid population growth on the availability of fish per capita and the effects of increased populations on degradation of coastal habitats through increased land use. Some of the problems caused by such pressures are already longstanding and need immediate attention. Priorities for action now are integrated coastal zone management to protect fish habitats, providing better access to tuna for food security, and restoration of sea cucumber fisheries.

Risks

Uncertainty remains about the magnitude of the projected effects of climate change on the sector due to the coarse resolution of the global climate models used to determine changes to surface climate, the tropical Pacific Ocean, and tuna stocks. Unless the next generation of global climate models succeeds in removing the significant existing biases, e.g. the overly zonal orientation of the South Pacific Convergence Zone, which limits confidence in projections of the rainfall and wind fields of the central-southern Pacific; and the warming associated with ENSO events, which is generally situated too far to the west and often occurs too frequently, it will be difficult to progressively improve vulnerability assessments and fine-tune adaptations.

The recommended adaptations may also fall short of the mark if the resolution of global climate models cannot be improved so that they 'see' PICTs, and downscaling methods for global climate models fail to provide robust projections of changes to surface climate and the ocean at scales meaningful to management in PICTs.

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