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Assessing the vulnerability of fisheries and aquaculture in the tropical Pacific to climate change – an update

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Assessing the vulnerability of fisheries and aquaculture in the tropical Pacific to climate change – an update

Introduction

Climate change is recognised as one of the key future drivers of fisheries and aquaculture in the region[1]. With assistance from AusAID, the Strategic Engagement Policy and Planning Facility has been working closely with the Fisheries, Aquaculture and Marine Environment Division to co-ordinate a comprehensive assessment of the vulnerability of the sector to climate change in the 22 Pacific Island countries and territories (PICTs). The assessment covers the area 130^{o}E and 130^{o}W and 25^{o}N and 25^{o}S, and has been designed to identify:

(1) The observed and projected changes to surface climate and the ocean in the tropical Pacific;
(2) The effects of these changes on the habitats that support fisheries and aquaculture in the region (the open ocean, coral reefs, mangroves and seagrasses, and freshwater rivers);
(3) The direct effects of changes to surface climate and the ocean, and the indirect effects of changes to fish habitats, on the distribution and abundances of the fish and invertebrates underpinning oceanic fisheries, coastal fisheries, freshwater fisheries and aquaculture in the Pacific Community;
(4) The implications of alterations to fish stocks due to climate change for economic development, government revenue, food security and livelihoods throughout the region;
(5) The management measures and policies needed to capitalise on the opportunities, and reduce the threats, expected to occur as a result of climate change; and
(6) The remaining uncertainty, gaps in knowledge, and the research required to fill them.

In making these assessments, we have focused on two future timeframes, 2035 and 2100, and two emissions scenarios, the B1 (low emissions) and A2 (high emissions) scenarios from the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Under the B1 scenario, the concentration of carbon dioxide (CO_2) in the atmosphere is projected to reach ~ 400 ppm by 2035, and 450–500 ppm by 2100. Under A2, concentrations of CO_2 are also projected to be ~ 400 ppm by 2035, but increase to 750–800 ppm by 2100. The current rate of global CO_2 emissions approximates the A2 scenario.

The vulnerability assessment involves contributions from 70 scientists from 30 institutions, guided by a broad-based Technical Working Group. It is due to be published as a peer-reviewed book[2], with a companion ‘Summary for Policy Makers’ in September, and will be launched at the high-level SPC Conference in Marshall Islands in October 2011.

Once the assessment is published, SPC will work with FAO to hold a workshop for all members of SPC in early 2012 to explain the key findings of the work in detail, and to help members identify priority adaptations and policies to: (1) reduce the threats to fisheries and aquaculture production from climate change, and (2) harness the opportunities expected to be created by the changing climate.

The purpose of this Information Paper is to summarise some of the key findings of the project so far. Full details will be available once the book and ‘Summary for Policy Makers’ are released in October 2011.

Changes in surface climate

The key features of the present-day surface climate, such as air temperature, rainfall, El Niño-Southern Oscillation (ENSO) events and cyclones, not only have a direct effect on the habitats that support freshwater fisheries and pond aquaculture, they affect many features of the ocean, such as sea surface temperature, salinity, oxygen and availability of nutrients, and therefore have a major effect on oceanic and coastal fisheries. The surface climate of the region is projected to change substantially due to global warming in the years ahead (Table 1).

Table 1. Projected changes to key features of Pacific surface climate relative to 1980–1999 values (see Lough et al. 2011 for details)[3].

<table>
<tr><td rowspan="2">Climate variable</td><td colspan="2">2035</td><td colspan="2">2100</td></tr>
<tr><td>B1</td><td>A2</td><td>B1</td><td>A2</td></tr>
<tr><td>Air temperature (°C)</td><td>+0.5–1.0</td><td>+0.5–1.0</td><td>+1.0–1.5</td><td>+2.5–3.0</td></tr>
<tr><td rowspan="3">Rainfall</td><td colspan="2">+5–20% in equatorial regions</td><td colspan="2">+10–20% in equatorial regions</td></tr>
<tr><td>5–10% decrease in subtropics</td><td colspan="3">5–20% decrease in subtropics</td></tr>
<tr><td colspan="4">▪ Extremes become more extreme</td></tr>
<tr><td>Cyclones</td><td colspan="4">▪ Number of tropical cyclones may decrease, but they may be more intense</td></tr>
<tr><td>El Niño-Southern Oscillation</td><td colspan="4">▪ ENSO events continue as a source of interannual climate variability
▪ Unclear as to whether changes in frequency and intensity of ENSO will occur</td></tr>
<tr><td>Pacific Decadal Oscillation</td><td colspan="4">▪ PDO continues to modulate Pacific basin climate and ENSO events
▪ Unclear as to whether this will change</td></tr>
<tr><td>Prevailing circulation</td><td colspan="4">▪ More vigorous hydrological cycle, and enhanced Hadley Circulation
▪ Expansion of area encompassed by ‘tropics’</td></tr>
</table>

Changes in the tropical Pacific Ocean

The projected changes to the key features of the tropical Pacific Ocean are summarised in Table 2. Many of these changes are expected to have direct effects on the distribution and abundance of tuna, especially the changes to water temperature and the eastward shift in the position of the western Pacific Warm Pool[4]. The effects of changes in water temperature, and the strength of major currents in the region are also likely to change the distribution and abundance of species important to coastal fisheries[5].

Table 2. Projected changes to key features of the tropical Pacific Ocean relative to 1980–1999 values (see Ganachaud et al. 2011 for details)[6].

Ocean feature	2035		2100	
	B1	A2	B1	A2
Currents	▪ South Equatorial Current decreases at the equator; Equatorial Undercurrent becomes shallower; ▪ South Equatorial Counter Current decreases and retracts westward			
Sea surface temperature	+0.7°C	+0.8°C	+1.0–1.5°C	+2.5–3.0°C
Ocean temperature at 80 m depth	+0.5°C		+1.0°C	+1.8°C
Warm Pool	▪ Extends eastward; water warms and area of warmest waters increases			
Equatorial upwelling	▪ Integral transport 9°S–9°N remains unchanged			
Eddy activity	▪ Probable variations where major oceanic currents change			
Nutrient supply	▪ Decrease due to increased stratification and shallower mixed layer, with a possible decrease of up to 20% under A2 by 2100			
Dissolved oxygen	▪ Possible decrease due to lower oxygen intake at high latitudes ▪ Possible increase near the equator due to decreased remineralization			
Waves	▪ Slight increase (up to 10 cm) in swell wave height; ▪ Patterns depend on ENSO and tropical cyclones			
Sea Level	+20–30 cm	+70–110 cm	+90–140 cm	
Ocean acidification				
Aragonite saturation (Ω)	n/a	3.3	3.0	2.4
Ω saturation horizon (depth)	n/a	456 m	n/a	262 m
pH	n/a	7.98	n/a	7.81

n/a = not available.

Open ocean food webs

The area of the ocean covered by the Pacific Community is divided into five ecological provinces, which differ in: size, water temperature, the depth of the surface mixed layer, net primary production of surface waters and the diversity and abundance of zooplankton and micronekton communities[7]. Taken together, these features determine the richness of the food webs for tuna, and for fish associated with reefs that feed on plankton. The five provinces are: Pacific Equatorial Divergence (PEQD), Warm Pool (WARM), North Pacific Tropical Gyre (NPTG), South Pacific Subtropical Gyre (SPSG) and Archipelagic Deep Basins (ARCH) (Figure 1). The areas of the Warm Pool and PEQD change regularly under the influence of ENSO events. The Pacific countries and territories that lie within each province, and the projected changes to the nature of these provinces due to climate change, are summarised in Table 3.

Figure 1. The five ecological provinces of the tropical Pacific Ocean.

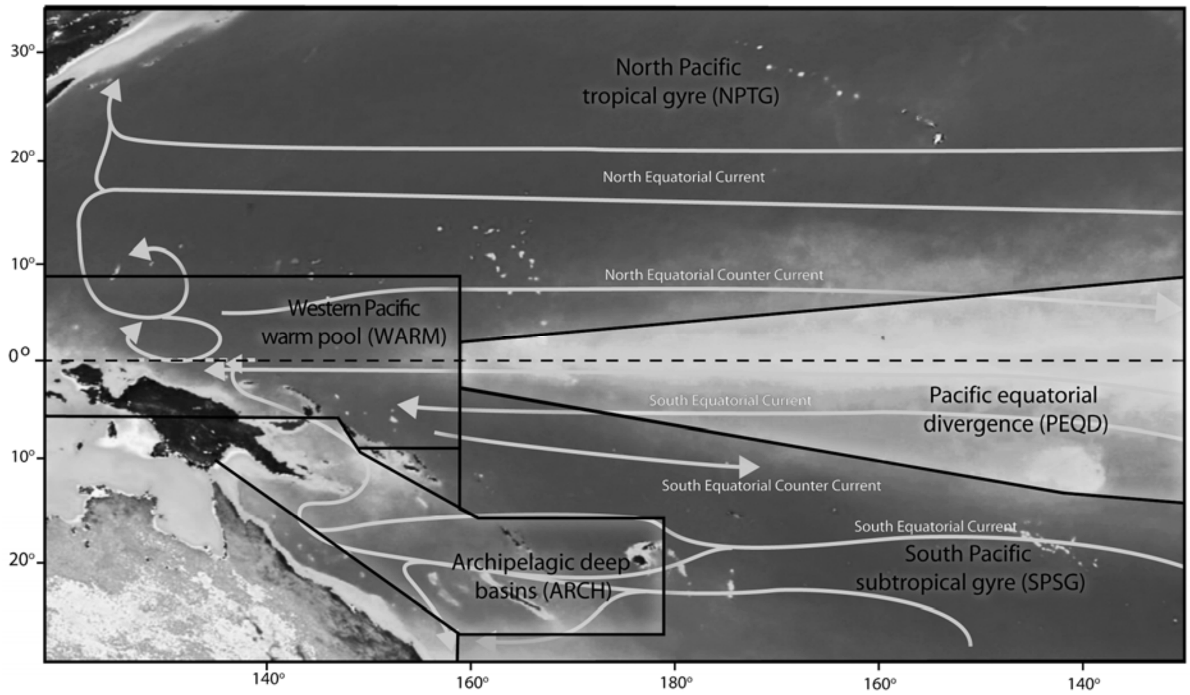

Table 3. Projected changes to the surface area, net primary productivity (NPP) and zooplankton biomass for the five ecological provinces. The Pacific Island countries and territories (PICTs) located within each province are also shown (note the some PICTs span two provinces or may lie within the Warm Pool or PEDQ, depending on ENSO events). The effects of the B1 and A2 scenarios have been combined for 2035, and for 2100. Where ranges of values are provided for the projected changes, the lower and higher values represent the projections for B1 and A2, respectively.

Province	PICT	2035	2100
PEDQ	Kiribati, Nauru, Tokelau, Tuvalu	Decrease in surface area of 20–27% as western boundary of PEQD moves eastwards from 180° to 170°W. Minor (2%) reduction in zooplankton biomass.	Decreases in surface area of 30–50% and movement of boundary to 160–150°W. A 2–4% increase in NPP and 3–6% decrease in biomass of zooplankton.
WARM	PNG, Solomon Islands, Nauru	Increase in surface area eastwards by 18–21%, with a 5–7% reduction in NPP and 3–6% decrease in biomass of zooplankton throughout the water column due to a deeper thermocline.	Increase in surface area eastwards by 26–48%, with a 9% reduction in NPP and 9–10% decrease in biomass of zooplankton throughout the water column due to deepening of the thermocline.
NTPG	Guam, FSM Marshall Islands, Palau, CNMI	Surface area increases limited to 1% as the province extends to the north. NPP decreases by 3–5% and zooplankton biomass declines by 1–3%.	Increase in surface of 1% but NPP decreases greatly (11–22%) and biomass of zooplankton declines by 10–18%.
SPSG	American Samoa, Cook Islands, French Polynesia, Niue, Pitcairn Islands, Samoa, Tonga, Tuvalu, Wallis and Futuna.	Surface area increases by 4–7%. A 4–5% reduction in NPP and 3–4% decrease in biomass of zooplankton.	Surface area increases by 7–14% and extends polewards, with a 3–6% reduction in NPP and 5–10% decrease in biomass of zooplankton due to a deeper thermocline.
ARCH	Fiji, New Caledonia, PNG, Vanuatu	No change in surface area. A 5–8% reduction in NPP and 5–6% decrease in biomass of zooplankton due to deepening of the thermocline.	No change in surface area. Greater (20–33%) reduction in NPP and 17–26% decrease in biomass of zooplankton due to deepening of the thermocline.

Coral reefs

The coral reefs of the region, which support much of the coastal fisheries production[5, 8], are expected to be degraded severely by the projected increases in sea surface temperature (SST), acidification of the ocean and possibly cyclones of greater intensity. The higher SST is expected to cause corals to bleach more often, whereas the increased atmospheric CO_2 dissolved in the ocean (the cause of ocean acidification) limits the amount of calcium carbonate (aragonite) available for corals to construct their skeletons. Both processes are projected to reduce coral cover, and affect growth of coral. In addition, the corals that do grow are expected to be weaker. This means that the percentage of live coral on reefs is likely to decrease (Table 4), and reefs are expected to be damaged more easily by wave surge from storms and cyclones. As the cover of live coral on reefs declines, the percentage cover of macroalgae is expected to increase. This is expected to fundamentally change the nature of coral reefs, although the altered structural complexity of reefs could still provide fish with shelter and food.

The projected effects of global warming and acidification of the ocean on coral reefs will be impossible to avoid, but they can be reduced by global reductions in greenhouse gases and good management of catchments so that other stresses on coral reefs, e.g., sediments and nutrients washed into coastal waters from catchments, are reduced. The percentage of live coral expected to occur on reefs in the future under strong and poor management are shown in Table 4. The detailed effects of increases in SST, acidification of the ocean and the possibility of stronger cyclones on coral reefs are described by Hoegh-Guldberg et al. (2011)[8].

Table 4. Projected percentage cover of live coral and macroalgae, and change in cover, on reefs in 2035 and 2100 for the B1 and A2 scenarios under poor and strong management.

Feature of coral reef	Management	2035		2100	
		B1	A2	B1	A2
Coral cover (%)	Strong	15–30	15–30	10–20	< 2
	Poor	15	15	< 5	< 2
Change in coral cover (%)	Strong	-25 to -65	-25 to -65	-50 to -75	> -90
	Poor	-65	-65	> -85	> -90
Algal cover (%)	Strong	40	40	50	> 95
	Poor	40–60	40–60	80	> 95
Increase in algal cover (%)	Strong	+130	+130	+170	> +300
	Poor	+130–200	+130–200	+270	> +300

Mangroves and seagrasses

In addition to coral reefs, several other coastal habitats support coastal fisheries. The most important of these are mangroves and seagrasses, although intertidal bare substrata also provide habitat for a variety of fish and invertebrates. The projected rises in sea level are expected to make it difficult for mangroves to cope with increased inundation by seawater. Mangroves should be able to migrate inland to find new areas within their salinity tolerances in some places. In others, they will be blocked from migrating inland due to steep terrain or construction of roads, etc. Even where mangroves are able to migrate, the accelerating rates of sea-level rise by 2100 are expected to 'overtake' the rate at which mangroves can re-establish, resulting in increasing losses of habitat.

The higher levels of runoff projected to occur as a result of the increases in rainfall in the tropics are expected to increase the turbidity of coastal waters, limiting the light available for seagrasses. The increased nutrients from runoff are also expected to increase the growth of the algae that occur on seagrasses, further increasing shading of the plants. The preliminary estimates of the possible losses in area of mangroves and seagrasses due to climate change are shown in Table 5.

Table 5. Projected estimated percentage change in area of mangrove and seagrass habitats in the tropical Pacific. Estimates cover a range for the region and include the perceived scope for the major areas of the existing ecosystems in the region to migrate inland. The majority of Pacific Island countries and territories (PICTs) are expected to have losses at the lower end of the ranges shown (Waycott et al. 2011)[9].

Habitat	2035		2100	
	B1	A2	B1	A2
Mangroves	-10 to > -10%	-10 to > -10%	-50 to -70%	-60 to -80%
Seagrass	< -5 to -20%	< -5 to -20%	-5 to -35%	-10 to -50%

Freshwater habitats

The projected increases in rainfall in tropical areas, and associated river discharge, are expected to increase the quality of all freshwater fish habitats. In the case of floodplain habitats, both the average area and the duration of inundation are likely to increase. However, such benefits will depend on careful management of catchments. Where forestry, agriculture and mining activities are not planned well, the increased rainfall will damage freshwater habitats through increased levels of sediment, nutrients and other pollutants. In subtropical areas (particularly New Caledonia), rainfall is projected to decrease, causing a corresponding reduction in freshwater fish habitat. The projected changes in area of fish habitat in tropical and subtropical areas are shown in Table 6.

Table 6. Projected estimated percentage change in the area of freshwater fish habitats in the tropical Pacific (assuming that catchments are well managed). See (Gehrke et al. 2011a)[10] for details of projected changes for individual countries and territories.

Region	2035		2100	
	B1	A2	B1	A2
Tropics	-5 to +10%	-5 to +5%	-5 to +20%	-5 to +20%
Subtropics	-5 to +5–10%	-5 to +5–10%	-10 to +10%	-20 to +20%

Oceanic Fisheries

Preliminary modeling of the effects of changes to water temperature, currents, dissolved oxygen levels, variations in NPP and the biomass of zooplankton/micronekton, and alterations in the position of the convergence zone between the Warm Pool and PEQD, indicate that there will be increases in the catches of skipjack in both the western and eastern part of the Pacific Community region in 2035 (Table 7). However, the increases in PICTs in the east will generally be far greater than those in the west. By 2100, the situation changes markedly and catches from many of the PICTs in the western part of the region are projected to decrease substantially, particularly under the A2 scenario (Table 7). In contrast, the catches of bigeye tuna are projected to decline from 2035 onwards, particularly under the A2 scenario in 2100. Modeling for yellowfin tuna and albacore is now in progress, and the trends for yellowfin tuna are expected to be similar to those for skipjack tuna. See Lehodey et al. (2011)[4] for details of the modeling methods.

Table 7. Preliminary projected percentage changes in catches of skipjack and bigeye tuna, relative to the 20-year average (1980–2000), under the B1 and A2 emissions scenarios in 2035 and 2100 for Pacific Island countries and territories (PICTs). Outputs were derived from the SEAPODYM model (Lehodey et al. 2011)[4].

PICT	Skipjack			Bigeye		
	B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
Melanesia						
Fiji	+26	+24	+33	+0.8	+0.7	-1.4
New Caledonia	+22	+19	+40	+1.1	+1.2	+6.0
PNG	+3	-11	-30	-4.5	-13	-27.9
Solomon Islands	+3	-5	-15	+0.1	-2.9	-7.3
Vanuatu	+18	+15	+26	-3.0	-6.1	-9.7

Table 7. (continued).

PICT	Skipjack			Bigeye		
	B1/A2 2035	B1 2100*	A2 2100	B1/A2 2035	B1 2100*	A2 2100
Micronesia						
FSM	+14	+5	-16	-3.5	-11.5	-32.5
Guam	+16	+10	-8	-6.7	-12.7	-32.7
Kiribati	+37	+43	+24	-0.7	-5.4	-16.6
Marshall Islands	+24	+24	+10	-3.1	-9.6	-26.9
Nauru	+25	+20	-1	-1.4	-6.6	-19.5
CNMI	+23	+22	+13	-0.3	-4.9	-22.6
Palau	+10	+2	-27	-3.9	-11.2	-45.2
Polynesia						
American Samoa	+41	+48	+58	-5	-8	-18
Cook Islands	+40	+50	+47	-3	-8	-15
French Polynesia	+41	+49	+77	-2	-8	-12
Niue		nea		-5	-8	-15
Pitcairn Islands		nea		-2	-4	-4
Samoa	+44	+49	+55	+1	+1	-4.2
Tokelau	+61	+69	+63	-3	-6	-16
Tonga	+47	+50	+58	-4	-5	-10
Tuvalu	+37	+41	+25	+3	+2	-6
Wallis and Futuna	+44	+49	+46	+0.4	-0.4	-7
Regional						
Total fishery	+19	+12	-7	+0.3	-9	-27
Western fishery**	+11	-0.2	-21	-2	-12	-34
Eastern fishery***	+37	+43	+27	+3	-4	-18

*Note that model simulations for A2 in 2050 can be used to approximate B1 in 2100, although it is important to note that while CO_2 emissions are similar, the multi-model mean of sea surface temperature is 0.18 (+0.23)^{o}C higher under B1 2100 than A2 2050; ** 15°N to 20°S and 130°E to 170°E; *** 15°N to 15°S and 170°E to 150°W; nea = no estimate available.

Notwithstanding the results from the preliminary modeling, indicating an eastward redistribution of tropical tuna stocks, there may well be subregional effects that run counter to this trend. For example, projections of a 10–20% increase in rainfall for the Sepik-Ramu and other large river systems in PNG could increase nutrient flows into the Bismarck Sea and more generally through the Indonesia-PNG archipelagos, retaining concentrations of tuna in these areas.

Coastal Fisheries

The wide range of species that contribute to subsistence and commercial coastal fisheries in the region can be divided into four main categories: demersal fish, near shore pelagic fish, invertebrates targeted for export, and invertebrates gleaned from subtidal and intertidal habitats. Tuna contribute to near shore pelagic fisheries, but are not considered here because the effects of climate change on these species are described above. Therefore, the near shore pelagic fish component refers only to species closely associated with coral reefs.

Coastal fisheries differ from oceanic fisheries and freshwater fisheries in that the productivity of all four categories mentioned above is projected to decline progressively under climate change. These declines are expected to occur to varying degrees through the direct and indirect effects of global warming and ocean acidification due to increases in greenhouse gas emissions.

Some of the main direct effects are expected to be due to the influences of: increases in sea surface temperature on reproductive success and development rate/survival of larvae; changes in currents and acidification of the ocean on recruitment success of juveniles, and greater rates of predation on many species of invertebrates caused by weaker shells resulting from reduced availability of calcium carbonate in sea water. The main indirect effects on coastal fisheries are expected to come from the projected degradation of the habitats that support coastal fisheries, particularly coral reefs but also mangroves, seagrasses and intertidal bare substrata.

The projected declines for each component of coastal fisheries expected to result from the combined direct and indirect effects of climate change are summarised in Table 8, and described in detail by Pratchett et al. (2011)[5].

Table 8. Projected percentage changes in production of the four categories of coastal fisheries, and total coastal fisheries production, due to climate change. The main potential indirect and indirect effects of climate change projected to cause future variations in production of coastal fisheries are also summarised.

Category	2035		2100		Main effects
	B1	A2	B1	A2	
Demersal fish	-2 to -5%	-2 to -5%	-20%	-20 to -50%	Habitat loss, and reduced recruitment (due to increasing temperature and reduced water movement)
Near shore pelagic fish*	0	0	-5 to -10%	-10 to -15%	Reduced production of zooplankton in food webs for non-tuna species
Targeted invertebrates	-2 to -5%	-2 to -5%	-10%	-20%	Habitat degradation, and declines in aragonite saturation due to ocean acidification
Shallow subtidal and intertidal invertebrates	0	0	-5%	-10%	Declines in aragonite saturation due to ocean acidification
Total coastal fisheries	Negligible	Negligible	-10 to -20%	up to -50%	

*Analysis does not include the tuna that also contribute to near shore pelagic fisheries.

Freshwater fisheries

The higher projected levels of rainfall and river flow are expected to result in slightly improved production from freshwater fisheries in tropical areas (Table 9) because river flow increases the availability and quality of habitats, provides cues for fish migration, and enhances reproduction and recruitment. Changes are expected to be negative or negligible in New Caledonia.

The projected increases in fisheries catches will be reduced in disturbed catchments where human activities have increased the sensitivity of fisheries species to climate change. Alterations in habitats as a result of climate change may also promote the spread of invasive alien species and increase interactions with indigenous species, and those species introduced for food security decades ago. These projections are of the most relevance to PNG, Fiji and Solomon Islands.

Table 9. Projected percentage changes in annual freshwater fisheries production based on expected future variation in rainfall and river flow (see Gehrke et al. 2011b for details)[11].

Region	2035		2100	
	B1	A2	B1	A2
Tropics	0	+2.5%	+2.5 to +7.5%	+2.5 to +12.5%
New Caledonia	+2.5%	0	-2.5%	0

Aquaculture

The projected effects of climate change on aquaculture are mixed. For farming of freshwater fish and freshwater prawns (*Macrobrachium* spp.) in ponds, production is expected to be enhanced by increased rainfall, river flows, and warmer temperatures (Table 10), provided ponds are located where they will not be affected by the flooding expected to occur during more extreme rainfall events, and possibly stronger cyclones. In PNG, the area suitable for farming tilapia in ponds is expected to increase as warmer temperatures permit these fish to be grown effectively at higher altitudes.

On the other hand, most of the commodities grown in coastal waters are likely to be affected adversely by climate change (Table 10). Rises in sea level will make it increasingly difficult to dry out shrimp ponds in New Caledonia between production cycles, increasing the risk of diseases due to residues in ponds, and requiring considerable investment in modifying or relocating ponds. Depending on future variations in water temperature, losses of cultured shrimp due to vibriosis in New Caledonia as seasons change may be exacerbated (or reduced). However, a potential positive outcome for shrimp farming in New Caledonia and Fiji is that warmer water temperatures may enable additional species of shrimp to be grown cost-effectively.

The increases in rainfall and higher water temperatures are expected to reduce the number of sites where seaweed can be grown effectively, and increase the incidence of epiphytic algae and ‘ice-ice’ disease. The survival of pearl oyster spat is likely to be reduced due to the reduced calcification of their shells as ocean acidification increases. There is also the possibility that the lower pH of the ocean may affect the deposition of nacre and pearl quality. Ocean acidification is also expected to impede the growth of ornamental products (e.g. coral fragments, giant clams and live rock), and sea cucumbers and trochus. Changes can also be expected in the distribution and abundance of wild juvenile rabbitfish due to variations in ocean currents, increases in water temperature and the possible effects of ocean acidification on larval behavior.

Table 10. Projected impacts of climate change on the main aquaculture commodities in the region. Note that impacts can be negative (-) or positive (+); L = low; M = medium; H = high (see Pickering et al. 2011 for details)[12].

Commodity	2035		2100	
	B1	A2	B1	A2
Tilapia and carp	L (+)	L (+)	L-M (+)	M (+)
Milkfish	L (+)	L (+)	L (+)	L (+)
Pearls	L (-)	L (-)	L (-)	M (-)
Seaweed	M (-)	M (-)	M-H(-)	H (-)
Shrimp	L (+)	L (+)	L (-)	L-M (-)
Marine ornamentals	L (-)	L (-)	M (-)	H (-)
Freshwater prawn	L (+)	L (+)	L (-)	L (-)
Marine finfish	L (-)	L (-)	L (-)	L-M (-)
Sea cucumbers	L (-)	L (-)	L (-)	L-M (-)
Trochus	L (-)	L (-)	L (-)	L (-)

Implications

There are several important implications of the projected changes in the productivity of oceanic, coastal and freshwater fisheries, and aquaculture for the region. To assist PICTs to understand the timelines involved with these implications we have also commented on projected outcomes for the A2 scenario in 2050. This has been done by using the projections for the A2 scenario in 2050, because the effects on the tropical Pacific Ocean, and therefore on fish habitats and fish, are comparable to B1 in 2100 (see footnote for Table 7).

Economic development and government revenue

The projected changes to the catches of tuna across the region are expected to have implications for the Gross Domestic Product (GDP) and/or government revenue for those PICTs where skipjack tuna are caught and/or processed. For those PICTs in the central and eastern Pacific where access fees from distant water fishing nations already provide a large proportion of government revenue (Kiribati, Tokelau and Tuvalu), there is expected to be substantial potential to negotiate for increased revenue between 2035 and 2050, with opportunities diminishing somewhat in 2100 (Table 11).

GDP in Marshall Islands is also expected to increase until 2100 as a result of the greater catches by the vessels operating from there (Table 11). Similarly, canning operations in American Samoa are expected to benefit until 2050 from the more eastern distribution of skipjack tuna (Table 11).

The projected reduction in catches from the EEZs of PNG and Solomon Islands in 2050 and 2100 (Table 7) are expected to affect the supply of fish to the canneries there unless arrangements are made to reduce the share of the catch taken by vessels from distant water fishing nations operating in these zones, or more fish are sourced from elsewhere in the region. In the event that this is not practical, the projected reductions in catch may affect the profitability of canneries and the opportunities for employment. From a national perspective, however, there would only be minor effects on economic development because the fisheries sector only makes a minor contribution to GDP in these relatively large regional economies (Table 11).

Table 11. Estimated percentage change to GDP and government revenues resulting from projected changes in the catch of skipjack tuna in 2035, 2050 and 2100 under the A2 scenario: L = lower and U = upper limit of estimates. Only PICTs were industrial fishing or processing contributes > 1% of GDP or government revenue are included.

PICT	Change to GDP (%)						Change to government revenue (%)					
	2035		2050		2100		2035		2050		2100	
	L	U	L	U	L	U	L	U	L	U	L	U
American Samoa	2.8	5.7	1.9	3.7	-1.1	-2.2	0.9	3.8	0.6	2.5	-0.4	-1.5
FSM	0.2	0.7	0.1	0.2	-0.2	-0.8	0.8	1.7	0.3	0.6	-0.9	-1.9
Kiribati	0	0	0	0	0	0	11.0	18.4	12.9	21.5	7.2	12.0
Marshall Islands	2.4	6.0	2.4	6.0	1.0	2.4	0.5	1.2	0.5	1.2	0.2	0.5
PNG	0.05	0.12	-0.16	-0.42	-0.45	-1.21	0.01	0.02	-0.02	-0.08	-0.06	-0.24
Nauru	0	0	0	0	0	0	2.5	6.3	2.0	4.9	-0.1	-0.3
Solomon Islands	0.06	0.16	-0.11	-0.28	-0.31	-0.77	0.01	0.16	-0.01	-0.28	-0.03	-0.77
Tokelau	0	0	0	0	0	0	1.2	9.1	1.4	10.3	1.3	9.5
Tuvalu	0	0	0	0	0	0	3.7	9.2	4.1	10.2	2.5	6.2

Food security

The key message here is that the projected changes to oceanic, coastal and freshwater fisheries, and aquaculture, on food security cannot be isolated from the powerful effects of population growth on the amount of fish likely to be available per capita in the future (Gillett and Cartwright 2010). Assuming that ~ 3 tonnes of fish can be harvested sustainably per km^2 of reef area per year[13], PICTs can be divided into three groups with respect to availability of fish for food security in the future.

1) PICTs that have sufficient coral reef to provide the 35 kg of fish person per year recommended for good nutrition, or the traditionally higher levels of fish consumption, for predicted population levels in 2035, 2050 and 2100, regardless of climate (Table 12).

Table 12. Estimates of fish available per capita in 2035, 2050, and 2100 for Pacific Island countries and territories (PICTs) in Group 1 under the A2 emissions scenario. Note that Group 1 also includes Pitcairn Islands (which is not included in the table).

PICT	Reef area (km^2)	Estimated potential fish yield per km^2 per year (tonnes)	Fish available per capita per year (kg)*		
			2035	2050	2100
New Caledonia	35,925	107,775	313	256	233
Marshall Islands	13,930	41,790	646	570	570
Palau	2496	7488	321	286	286
Cook Islands	667	2000	115	99	105
Tokelau	204	612	495	446	446

*includes coastal fish and invertebrates.

2) PICTs that have sufficient areas of coral reef to produce the fish needed for predicted population levels in the future, but where it will be difficult to distribute the potential harvests to urban centres because of the great distances between islands, atolls and reefs (Table 13). These circumstances are not expected to change under the A2 scenario, except in Kiribati from 2035 onwards, and French Polynesia in 2100 (Table 13), where total national coastal fisheries resources are unlikely to be sufficient to meet traditional levels of fish consumption, even if they can be distributed effectively to population centres.

Table 13. Estimates of fish available per capita in 2035, 2050, and 2100 for Pacific Island countries and territories (PICTs) in Group 2 under the A2 emissions scenario.

PICT	Reef area (km^2)	Estimated potential fish yield per km^2 per year (tonnes)	Fish available per capita per year (kg)*		
			2035	2050	2100
FSM	15,074	45,222	418	354	236
French Polynesia	15,126	45,378	131	108	57 [b]
Kiribati	4320	12,960	86[a]	66 [a]	26 [b]
Niue	56	168	125	111	80
Tonga	5811	17,433	145	116	50
Tuvalu	3175	9525	711	564	234
Wallis and Futuna	932	2796	197	170	96

*includes coastal fish and invertebrates; a = availability of reef-associated fish per capita is less than current rates of traditional fish consumption; b = availability of reef-associated fish per capita is less than the 35 kg recommended for good nutrition.

3) PICTs where there are projected to be (often very large) gaps between the fish and invertebrates available from coastal and freshwater fisheries combined, and the recommended 35 kg per capita per year recommended for good nutrition (Table 14), both now and in the future.

Climate change is expected to reduce availability of fish per capita for PICTs in Group 3 by only 1–2 kg, except Fiji, Solomon Islands and Samoa, because the effects of population growth on availability of reef-associated fish and invertebrates per capita are already profound (Table 14), leaving little scope for climate change to increase the gap further. Under the A2 scenario, Fiji will need access to another 7 kg of fish per capita in 2050, and 15 kg in 2100. In Solomon Islands, 8 kg of fish per person will need to be made available for food security in 2035, increasing to 16 kg in 2050 and 24 kg in 2100. The corresponding quantities for Samoa are 6 kg in 2035, 9 kg in 2050 and 16 kg in 2100.

The progressive decline in the relative contribution of coastal and freshwater fisheries to the fish needed for food security (due to the limits on production from these habitats and the effects of climate change on stocks) will need to be filled mainly with tuna (Appendix 1). The role of tuna in providing the fish needed for food security for PICTs in Group 3 in the future is profound – not only does the amount of fish needed increase over time, tuna has to supply an increasing percentage of the total fish required (Appendix 1). It is fortunate that the region has rich tuna resources, and that tuna are likely to be more abundant in the EEZs of many of the PICTs in Group 3 in the future. Pond aquaculture also has potential to make locally important contributions, possibly amounting to ~ 10% of total fish required nationally by 2100 in some PICTs. It is also fortunate that freshwater pond aquaculture is expected to be favoured by climate change.

Table 14. Gap between recommended annual per capita fish consumption and the estimated annual per capita supply of fish from coastal and freshwater fisheries for Pacific Island countries and territories (PICT) in Group 3 in 2010, 2035, 2050 and 2100. These projected gaps do not incorporate the impacts of climate change.

PICT	Reef area (km^2)	Coastal fish available per year (tonnes)	Freshwater fish available per year (tonnes)**	Total fish available per year (tonnes)	Total fish available per capita per year (kg)				Gap in fish needed for good nutrition per capita per year (kg)			
					2010	2035	2050	2100	2010	2035	2050	2100
American Samoa	368	1104	1	1105	17	13	11	8	18	22	24	27
Fiji	10,000*	30,000	4146	34,146	40	35	32	26	+(5)	0	3	9
Guam	238	714	3	717	4	3	3	2	31	32	32	33
Nauru	7	21	0	21	2	1	1	1	33	34	34	34
PNG	22,000*	66,000	17,500	83,500	12	8	6	4	23	27	29	31
CNMI	250	750	0	750	12	10	9	9	23	25	26	26
Samoa	2000	6000	10	6100	33	30	29	25	2	5	6	10
Solomon Islands	8535	25,605	2000	27,605	50	28	22	14	+(15)	7	13	21
Vanuatu	1244	3732	80	3812	16	9	7	4	19	26	28	31

*Preliminary estimates only; **Data from Gillett (2009)[14].

Key Adaptations

Economic development and government revenue

A major re-distribution of tuna fishing activity towards the central Pacific would create challenges for some PICTs and opportunities for others. In general, it will be important that the various layers of management, but particularly the Parties to the Nauru Agreement (PNA) in whose EEZs a significant portion of the regional tuna catch occurs, further develop their management systems to ensure flexibility to cope with a potentially changing spatial distribution of the fishing effort. In short, continued effective management of fishing effort will be needed to capitalise on any new opportunities arising from the projected changes in distribution and abundance of tuna.

For the PNA, the Vessel Days Scheme (VDS) implemented for the purse-seine fishery within their EEZs, and the one under development for the longline fishery, provide a good option for adapting to climate change. Essentially, these schemes allocate fishing effort among the EEZs according to agreed criteria and allow for transferability of these rights among members. The transferability aspect of the VDS has recently come into effect, and will need to be implemented and adjusted in the future if changing distributions of fishing effort are to be managed in an orderly fashion. The VDS has the potential to operate in a similar way to the 'cap and trade' systems being considered by many countries worldwide to limit their emissions of CO_2.

Food Security

The key adaptations needed to ensure that PICTs provide access to sufficient fish for good nutrition of their populations in the future are described below. While they apply mainly to PICTs in Group 3, they are also relevant to PICTs in Groups 1 and 2.

1) ***Improve management of natural resources:*** Stocks of coastal and freshwater fish and invertebrates, and the habitats they depend on, will need to be managed as well as possible to minimise the size of the emerging gap in the amount of fish needed for good nutrition, and the quantity of fish that can be harvested sustainably. Good management will improve the opportunities for stocks and habitats to deliver their potential sustainable yields; it will also enable them to fulfil their potential natural capacity to adapt to climate change. Stocks of coastal and freshwater fish need to be managed with simple practical measures15, incorporating a community-based ecosystem approach (see Information Paper No. 1), to maintain spawning biomass within sustainable bounds. The most important management action that PICTs can apply to help maintain the coral reefs, mangroves and seagrass that support coastal fisheries, and freshwater fish habitats, is to regulate the development of agriculture, forestry, mining and other large developments in catchments to retain the vegetation needed to prevent soil erosion and sedimentation.

2) ***Diversify access to tuna:*** In rural coastal areas, networks of low-cost FADs anchored inshore should be constructed as part of the national infrastructure for food security. This will enable both subsistence fishers and small-scale fishers supplying local markets to access yellowfin and skipjack tuna more frequently. These FADs should be placed where they attract primarily tuna, rather than the other large pelagic fish that are closely associated with reefs. In urban centres, incentives should be provided for new enterprises that store, distribute and sell lower grade (small) tuna and bycatch landed by industrial fleets, so that more fish is available at reasonable prices.

   For PNG and Solomon Islands, these adaptations will involve allocating an increasing proportion of their annual average tuna catches over time to provide the quantities of fish recommended for good nutrition of their populations (Appendix 1). On the basis of population growth alone, these proportions needs to reach 22% and 16% for PNG and Solomon Islands, respectively in 2050, increasing to 43% and 38% in 2100. These proportions increase marginally in 2050, and to ~ 60% for PNG and ~ 45% for Solomon Islands by 2100, due the effects of climate change (A2 emissions scenario).

   Although some of this allocation will need to be given directly to coastal communities to catch tuna around FADs, it is expected to have little effect on the profitability of tuna canneries in PNG and Solomon Islands because: 1) these two PICTs already market substantial proportions of their products on the domestic market, and 2) canned tuna is one of the most practical ways of making fish available to their rapidly growing populations.

3) ***Promote pond aquaculture:*** Although tuna will need to fill the majority of the gap in fish supply (Appendix 1), pond aquaculture needs to be developed and promoted in inland areas PNG, Fiji and Solomon Islands. Care will be needed to do this is in a way that minimises the effects on freshwater biodiversity (see Working Paper No. 5). The use of fish for food security in inland areas of PNG is expected to remain a problem, however, because pond culture may only have the potential to supply 1–4 kg per person per year. Unless the benefits of the mining and gas boom in PNG flow to inland communities, they are unlikely to have the income to purchase the tuna produced by the expanding number of canneries in the country.

PICTs in Group 2 will also need to apply these adaptations, as appropriate, to supply fish to urban centres. Kiribati in particular will need to provide access to more fish to maintain its traditionally high levels of fish consumption as the combined effects of population growth and climate change reduce the potential availability of fish. Investments in low-cost inshore FADs around Tarawa, and small-scale vessels to fish around them, will be needed to provide the urban population with access to tuna to fill the gap between the fish needed for food security and the fish available from reefs. In the event that such investments are not effective, Kiribati will need to consider negotiating with industrial vessels operating within their EEZ to land a proportion of tuna to supply the local market. Similar, considerations are also expected to apply to Tahiti in French Polynesia under the A2 scenario in 2100.

Any risks associated with investing in fishing around inshore FADs can be expected to reduce over time, because skipjack and yellowfin tuna are projected to become more abundant in most PICTs in Group 2 under the B1 and A2 emissions scenarios (Table 7), provided there is effective management of fishing effort across the region.

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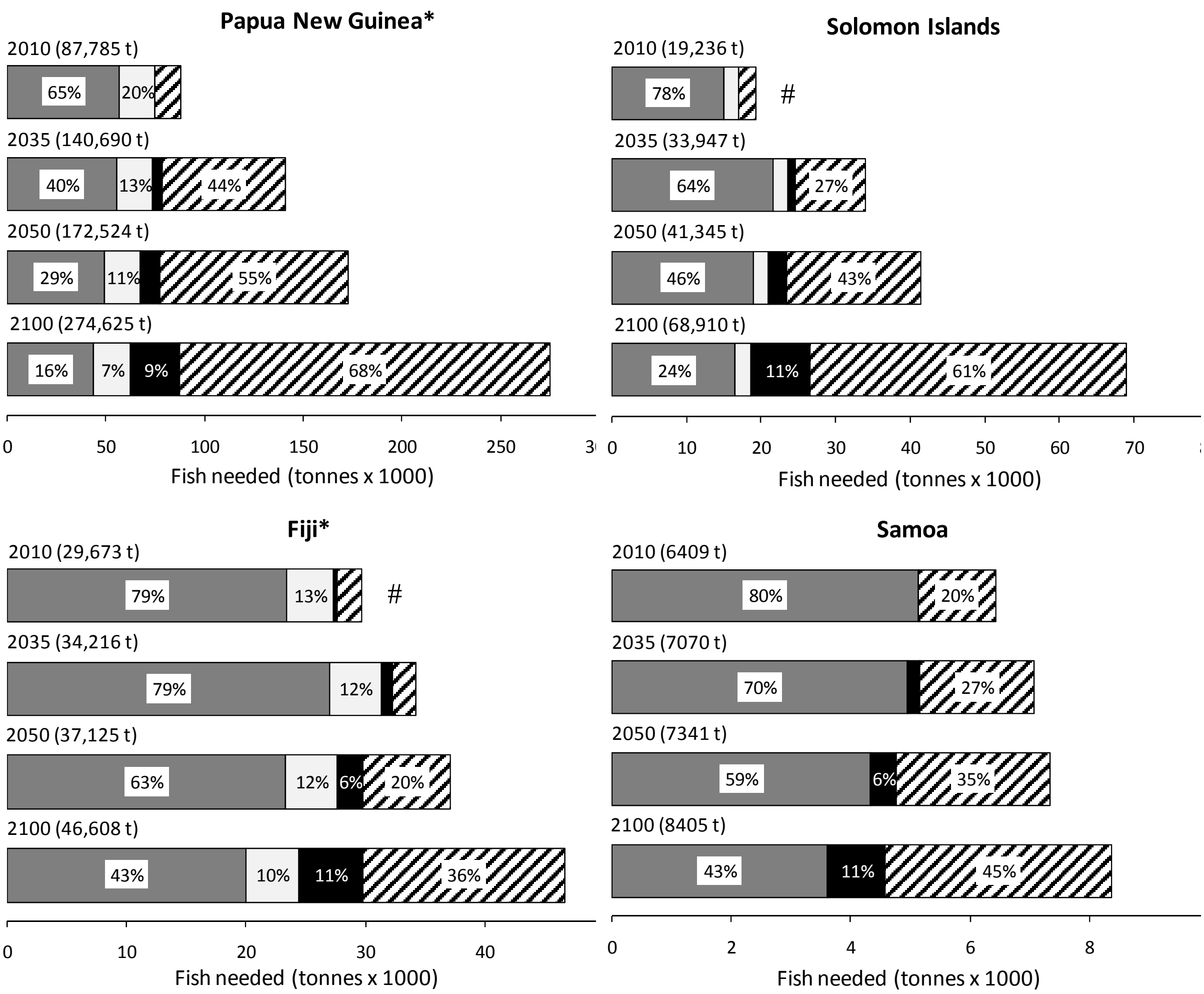
Appendix 1. Estimated contributions of tuna ( ), coastal fisheries ( ), freshwater fisheries ( ) and aquaculture ( ), in tonnes (t) and percentages, required to supply 35 kg of fish per capita per year for Pacific Island countries and territories in Group 3 in 2010, 2035, 2050, 2100. Contributions from coastal fisheries are based on estimated sustainable production of 3 tonnes per km^2 per year and have been adjusted for the projected effects of climate change (A2 emissions scenario) on the demersal fish, non-tuna near shore pelagic fish and subtidal and intertidal invertebrates that comprise coastal fisheries. * indicates PICTs that do not currently have per capita fish consumption of 35 kg per year; for all other PICTs estimates are limited to supplying 35 kg per capita even though traditional rates of fish consumption have been greater. The fish required for food security in PNG in the future is based on the estimated 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. # indicates that coastal fisheries alone have the potential to provide 35 kg of fish per person in 2010 but estimated contributions from tuna and freshwater fisheries are also shown. ‘Tuna’ also includes bycatch from industrial tuna fishing vessels.



Appendix 1 (continued)