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Effects of climate change on oceanic fisheries in the tropical Pacific: implications for economic development and food security

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Abstract The four species of tuna that underpin oceanic fisheries in the tropical Pacific (skipjack, yellowfin, bigeye and albacore tuna) deliver great economic and social benefits to Pacific Island countries and territories (PICTs). Domestic tuna fleets and local fish processing operations contribute 3–20 % to gross domestic product in four PICTs and licence fees from foreign fleets provide an average of 3–40 % of government revenue for seven PICTs. More than 12,000 people are employed in tuna processing facilities and on tuna fishing vessels. Fish is a cornerstone of food security for many PICTs and provides 50–90 % of dietary animal protein in rural areas. Several PICTs have plans to (1) increase the benefits they receive from oceanic fisheries by increasing the amount of tuna processed locally, and (2) allocate more tuna for the food security of their rapidly growing populations. The projected effects of climate change on the distribution of tuna in the tropical Pacific Ocean, due to increases in sea surface temperature, changes in velocity of major currents and decreases in nutrient supply to the photic zone from greater stratification, are likely to affect these plans. PICTs in the east of the region with a high dependence on licence fees for government revenue are expected to receive more revenue as tuna catches increase in their exclusive economic zones. On the other hand, countries in the west may encounter problems

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securing enough fish for their canneries as tuna are redistributed progressively to the east. Changes in the distribution of tuna will also affect the proportions of national tuna catches required for food security. We present priority adaptations to reduce the threats to oceanic fisheries posed by climate change and to capitalise on opportunities.

1 Introduction

The 22 Pacific Island countries and territories (PICTs) lie between ~25 °N and 25 °S and 130 °E to 130 °W and their combined exclusive economic zones (EEZs) cover >27 million km^2—an area almost three times larger than the land area of the United States of America. Another important feature of PICTs is that many of them depend heavily on oceanic fisheries for economic development and food security (Bell et al. 2009; Gillett 2009).

The great benefits PICTs receive from oceanic fisheries are now at risk from the multiple drivers affecting the sector, such as population growth, urbanisation, the global economy, technological advances and fuel costs (Gillett and Cartwright 2010). The economies of several PICTs also have to cope with the effects of the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation on the benefits they receive from the abundant skipjack tuna—the prime fishing areas for this species change by up to 3,000–4,000 km depending on the prevailing ENSO conditions (Lehodey et al. 1997; Lehodey et al. 2011). As a result, PICTs recognise that their plans to optimise the economic and social benefits from tuna in the face of the many drivers affecting oceanic fisheries are likely to be affected by the changing climate.

The Secretariat of the Pacific Community has recently assessed the vulnerability of fisheries and aquaculture in the tropical Pacific to climate change to assist PICTs adapt to the projected alterations in the resources that underpin the sector (Bell et al. 2011a). Here, we draw on this vulnerability assessment to (1) describe the main oceanic fisheries in the tropical Pacific; (2) summarise the existing benefits derived by PICTs from oceanic fisheries; (3) outline the plans PICTs have to maintain or improve these benefits; (4) examine how tuna resources may be affected by a high greenhouse gas emissions scenario for the remainder of the century; (5) evaluate the implications of projected changes in the contributions of oceanic fisheries to the economies of PICTs and their coastal and urban communities; and (6) identify the key adaptations needed to reduce the threats and capitalise on the opportunities.

2 Main oceanic fisheries

Four species of tuna support the main oceanic fisheries in the Western and Central Pacific Ocean (WCPO): skipjack tuna *Katsuwonus pelamis*, yellowfin tuna *Thunnus albacares*, bigeye tuna *T. obesus* and albacore *T. alalunga*. These tuna species are caught by two separate industrial fisheries (1) a surface fishery comprised mainly of purse-seine and pole-and-line fleets targeting skipjack and yellowfin tuna to supply canneries; and (2) a longline fishery, which targets mature bigeye and yellowfin tuna for the sashimi trade and other high-value markets, as well as albacore for canning. The catch made by the surface fishery is ~10 times greater than the longline catch (Williams and Terawasi 2010). Tuna also make significant contributions to artisanal fisheries in nearshore waters (Pratchett et al. 2011).

For the 5-year period 2006–2010, the total annual catch of all tuna species from the WCPO was ~2.4 million tonnes, with ~50 % coming from the EEZs of PICTs (Fig. 1). Purse seining accounted for ~85 % of the fish caught by the surface fishery and most (75 %) of the fish taken by this method were skipjack tuna (Williams and Terawasi 2010). The remainder

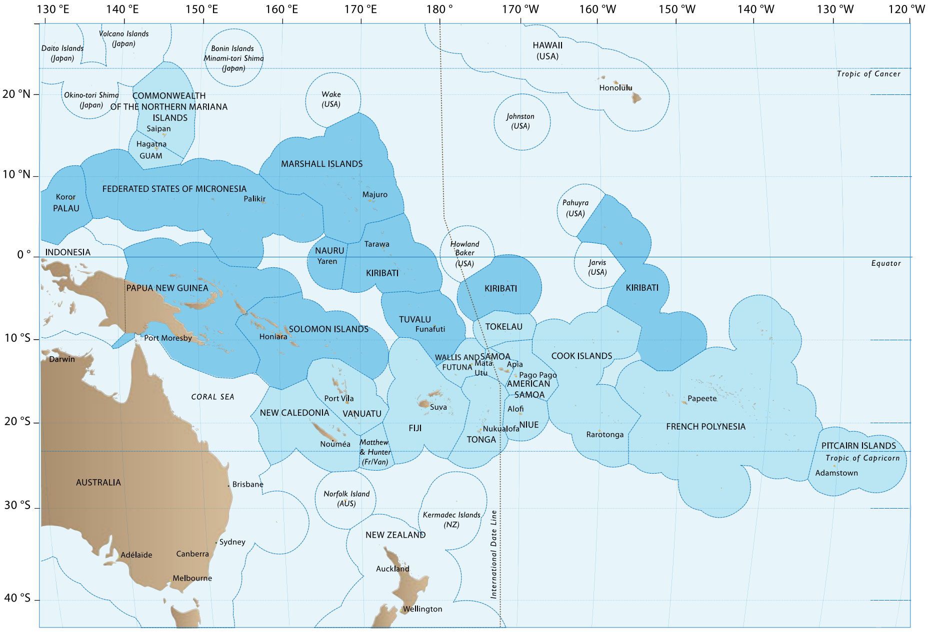

Fig. 1 Estimated exclusive economic zones (EEZs) of Pacific Island countries and territories (PICTs). The EEZs of countries that are the Parties to the Nauru Agreement are shown in *darker blue*. Note that not all EEZs of PICTs have been officially delineated under the United Nations Convention on the Law of the Sea

of the purse-seine catch was mainly yellowfin tuna (~20 %) and bigeye tuna (~5 %). The spawning biomass and fishing mortality of skipjack and yellowfin tuna in the WCPO remain within the limits for maximum sustainable yield but overfishing of bigeye has been occurring in recent years, apparently due to the widespread use of floating fish aggregating devices (FADs) by purse-seine fleets (Lehodey et al. 2011).

Between 1999 and 2008, the great majority of the catch by the surface fishery taken from the waters of PICTs came from the EEZs of the eight countries that are the Parties to the Nauru Agreement (PNA) (Fig. 1) (Williams and Terawasi 2010). The volumes and values of fish landed over this 10-year period are a reasonably good indication of the relative importance of the catches in each EEZ because they average out some of the ENSO events that influence the distribution of skipjack tuna and fishing effort across the region (Lehodey et al. 1997; 2011).

3 Existing benefits derived from oceanic fisheries

Domestic tuna fleets and local fish processing operations make substantial contributions to gross domestic product (GDP) in the region–between 3 % and ~20 % of GDP is derived from these activities in four PICTs (Gillett 2009). Licence fees from distant water fishing nations (DWFNs) involved in the surface and longline fisheries make even greater contributions to government revenue. Such contributions average between 3 % and 40 % of government revenue for seven PICTs (Gillett 2009). Oceanic fisheries are also an important source of jobs in the region—more than 12,000 people are employed in tuna canneries or processing facilities, or on tuna fishing vessels (Gillett 2009).

Fish is an important part of the diet of Pacific Island people—fish consumption is at least 2–4 times the global average in more than half of all 22 PICTs and fish often makes up 50–90 % of dietary animal protein in rural areas (Bell et al. 2009). Although much of this fish comes from coastal demersal fish species, ~30 % of the coastal fisheries catch (by weight) is large pelagic (often oceanic) fish species caught by nearshore fisheries (Pratchett et al. 2011). In 10 of the 22 PICTs, tuna are estimated to make up 50–75 % of the nearshore pelagic fish catch.

4 Plans to increase the benefits from oceanic fisheries

The economic gains for PICTs from oceanic fisheries are much greater when the catches from locally-based purse-seining and longlining operations are landed for processing onshore. Each additional 100,000 tonnes of tuna retained from the surface fishery for processing in the region has the potential to create 7,000 jobs (FFA 2010). As a result, some PICTs are taking steps to capture wider economic benefits from tuna resources by attracting foreign investment into locally-based fishing and processing operations. In recent years, >USD 60 million has been invested in new tuna processing plants in the region and more facilities are proposed in Papua New Guinea (PNG) and Solomon Islands.

However, some of the smaller island states, e.g. Kiribati, Nauru and Tuvalu, do not have all the attributes needed for large-scale onshore processing, i.e. suitable land, ample freshwater and low labour costs. For these countries, licence fees from DWFNs represent the most important way to derive benefits from tuna. Accordingly, PNA members are collectively exploring ways to maximise their financial returns from providing access to their EEZs (Pareti 2009). PNA members are in a powerful position to do this because they supply ~40 % of the world's canning tuna.

The plans that several PICTs are developing to provide their growing populations with access to the fish required to maintain their traditional levels of fish consumption, or supply the 35 kg of fish per person per year recommended for good nutrition (SPC 2008), will depend on increased allocations of tuna from oceanic fisheries (Bell et al. 2009). These plans are being instigated because production of demersal coastal fisheries in many PICTs (Newton et al. 2007; Pratchett et al. 2011) is either unable to meet future demand, or is unlikely to be distributed effectively from remote fishing areas to population centres (Bell et al. 2011b).

5 Projected effects of climate change on fisheries resources

The four main species of tuna in the tropical Pacific Ocean are projected to be exposed to increased water temperatures, changes in the strength of major currents, reduced oxygen and pH levels, and less productive food webs (Ganachaud et al. 2011; this volume; Le Borgne et al. 2011). Preliminary modelling by Lehodey et al. (2011) indicated that catches of skipjack tuna are likely to increase across much of the WCPO by 2035 under the Intergovernmental Panel on Climate Change A2 emissions scenario, particularly in the eastern part of the region (Table 1). By 2050, catches are projected to increase by >40 % relative to the 1980–2000 average in the east, and start to decrease in the west (Table 1), as the fish follow the relocation of their preferred water temperatures and prime feeding grounds at the

Table 1 Projected percentage changes in catches of skipjack tuna, relative to the 20-year average for 1980–2000, under the A2 emissions scenario in 2035, 2050 and 2100 within the exclusive economic zones of Pacific Island countries and territories (PICTs). Projected changes are also shown for the combined fishery in the eastern and western areas of the region, and for the total region. Information derived from the SEAPODYM model (Lehodey et al. 2011)

PICT	2035	2050	2100
Western region (west of 170 °E)			
FSM	+14	+5	−16
Guam	+16	+10	−8
Marshall Islands	+24	+24	+10
Nauru	+25	+20	−1
New Caledonia	+22	+19	+40
CNMI	+23	+22	+13
Palau	+10	+2	−27
Papua New Guinea	+3	−11	−30
Solomon Islands	+3	−5	−15
Vanuatu	+18	+15	+26
Eastern region (east of 170 °E)*			
American Samoa	+41	+48	+58
Cook Islands	+40	+50	+47
Fiji	+26	+24	+33
French Polynesia	+41	+49	+77
Kiribati	+37	+43	+24
Samoa	+44	+49	+55
Tokelau	+61	+69	+63
Tonga	+47	+50	+58
Tuvalu	+37	+41	+25
Wallis and Futuna	+44	+49	+46
Regional			
Western fishery (15 °N to 20 °S and 130 °E to 170 °E)	+11	−0.2	−21
Eastern fishery (15 °N to 15 °S and 170 °E to 150 °W)	+37	+43	+27
Total fishery	+19	+12	−7

* no estimates available for Niue and Pitcairn Islands

convergence of the Warm Pool and Pacific Equatorial Divergence Province (Ganachaud et al. 2011; Lehodey et al. 2011; Le Borgne et al. 2011). By 2100, the preliminary modelling also indicated that average skipjack catches in the west are projected to decrease by ~20 % and that the projected increases in the east could be reduced from >40 to <30 %, leading to an overall decrease in catches of ~7 % across the region (Table 1). The decline in catches by 2100 is expected to occur as a result of lower primary productivity due to increased stratification of the water column and reduced nutrient supply to the photic zone (Ganachaud et al. 2011; Le Borgne et al. 2011). More recent modelling by Lehodey et al. (this volume) to correct temperature anomalies suggests that the decreases in skipjack tuna catch in the west may not occur until 2070.

The production of the demersal fish associated with coral reefs and other inshore habitats across the region, which presently provides much of the fish eaten by Pacific Island people, is projected to decrease by 2–5 % by 2035, 20 % by 2050[1] and 20–50 % by 2100 under the A2 emissions scenario (Pratchett et al. 2011). These declines are expected to occur due to (1) the direct effects of increased sea surface temperature, ocean acidification and changes to ocean currents (Ganachaud et al. 2011) on the reproduction, dispersal, survival and growth of demersal fish; and (2) the indirect effects of climate change, i.e. degradation of the coral reef, mangrove, seagrass and intertidal habitats that support coastal fish species (Bell et al. 2011a).

6 Implications

6.1 Economic development

To assess the potential effects of projected changes to catches of skipjack tuna on the economies of PICTs, we estimated the lower and upper bounds of projected contributions of these catches to GDP and government revenue in 2035, 2050 and 2100 under the A2 scenario. This analysis was based on (1) the variation in estimates of GDP and government revenue derived from the surface tuna fishery (which is dominated by skipjack tuna) between 1999 and 2008, and the projected changes in skipjack tuna catch from the preliminary modelling by Lehodey et al. (2011). Thus, if the contributions of the skipjack tuna catch to GDP are estimated to vary between 5 % and 10 %, and the catch is projected to rise by 10 %, then the increased contribution to the lower estimate of GDP due to the greater catch is 0.5 %, and the contribution to the upper estimate is 1.0 %.

In making these assessments, we assumed that (1) variations in catch will have similar impacts on GDP and government revenue; (2) tuna prices, GDP, levels of taxation, and the value-added component of purse-seine and pole-and-line fishing operations, remain constant, relative to 1999–2008 levels; (3) the balance between catches by locally-based fleets (which contribute to GDP) and DWFNs (which do not) stays the same; and (4) fishing effort remains constant.

The last assumption is unlikely to hold for many areas within the region because fishing effort usually increases where catch per unit effort (CPUE) improves, and decreases where CPUE declines. Exceptions to this general pattern can be expected for fleets fishing close to canneries even when CPUE decreases due to the greater profitability of such fishing operations. Overall, this means that the values in this analysis are likely to be underestimates. However, without coupled biophysical and fleet dynamics models, we cannot include such complexity in our assessment.

Our analysis is restricted to PICTs where the average contribution of the surface fishery to GDP or government revenue was >1 % over the period 1999–2008 (Table 2), or where large quantities of tuna were transshipped or processed. The estimated impacts on the lower and upper contributions to GDP and government revenue are based on the projected catches of skipjack tuna in the EEZ of each PICT (Table 1). However, because the post-harvest processing sector in American Samoa is supplied by fish caught throughout the fishery,

[1] Projections for the B1 emissions scenario in 2100 were used as a surrogate for A2 in 2050, noting that the multi−model mean of sea surface temperature is 0.18 (±0.23)°C higher under B1 2100 than A2 2050 (Bell et al. 2011a).

Table 2 Estimated changes in percentage contributions of skipjack tuna catches to GDP and government revenue in selected Pacific Island countries and territories (PICTs), relative to 1999–2008, in 2035, 2050 and 2100 under the A2 emissions scenario. Estimates are based on projected alterations in the catch of skipjack tuna from preliminary modelling (Table 1). Lower (L) and upper (U) limits are shown for the estimates, together with the average contributions of skipjack tuna catches to GDP and government revenue for the period 1998–2008. Only PICTs where industrial fishing or processing contributes >1 % to GDP or government revenue are included (source: Bell et al. 2011b)

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

[a] Located west of 170°E

[b] located east of 170°E

the estimated effects on GDP in American Samoa are based on the projected catches across the entire region (Table 1).

The expected improvements in catch by 2035 (Table 1) lead to projected increases in GDP and government revenue, particularly for those PICTs in the east of the region (Table 2). The most significant increases to GDP associated with the projected changes in catch are for American Samoa (3–6 %) and Marshall Islands (2–6 %). The greatest expected increases in government revenue by 2035 are for Kiribati (11–18 %), Tuvalu (4–9 %), Tokelau (1–9 %) and Nauru (2–6 %) (Table 2).

For PICTs in the east, the general level of benefits to GDP and government revenue projected for 2035 are expected to continue in 2050 (Table 2). On the other hand, projected decreases in catch of 11 % in PNG and 5 % in Solomon Islands by 2050 (Table 1) are expected to lead to reduced economic benefits. However, due to the relatively large size of their economies, GDP is estimated to decline by only 0.1–0.4 % in both countries, and government revenues are expected to fall by only 0.1 % in PNG and 0.3 % in Solomon Islands (Table 2).

By 2100, the expected decline in catches of ~20 % in the larger component of the fishery in the west more than offsets the projected increases of 25–30 % in the east. The projected 30 % decline in catches of skipjack tuna in the EEZ of PNG by 2100 (Table 1) is particularly significant, although it is estimated to result in a reduction of only up to 1.2 % in GDP, and 0.2 % in government revenue (Table 2). The projected decreases in catches from Solomon Islands and the Federated States of Micronesia (FSM) of ~15 % are also expected to cause reductions of about 0.8–1 % in GDP, and ~1–2 % in government revenue in both countries, respectively. In the east, Kiribati and Tuvalu are projected to continue to receive increased economic benefits from skipjack tuna in 2100, albeit at lower levels than in 2035 and 2050 (Table 2).

The analyses presented here are preliminary and should be interpreted with caution—they provide only an indication of the direction and magnitude of possible economic impacts and need to be improved by matching the baselines for projected catches (1980–2000) with the baselines for the contributions to GDP and government revenue (1999–2008). The more recent modelling by Lehodey et al. (this volume) suggests that the projected benefits of the region-wide increase in skipjack catch may persist until around 2070, and then decline progressively. Nevertheless, re-assessment of the possible implications for GDP and government revenue are probably best deferred until the results of continued modelling show uniform trends. Such future modelling should incorporate outputs from the new generation of global physical climate models linked to biological parameters (e.g. prey for tuna) derived from multiple ecosystem models and fleet dynamics models.

On balance, the projected changes in the skipjack tuna catch from the preliminary modelling could result in more advantages than disadvantages for the region. The possible advantages are that Kiribati, Tuvalu, Tokelau and Nauru are likely to have opportunities to negotiate increased licence fees. More modest benefits to GDP and/or government revenue are also expected for American Samoa, FSM and Marshall Islands but perhaps only until 2050. The potential disadvantages are that the progressive movement of skipjack tuna, and ultimately fishing effort, further to the east may eventually affect the contribution of fishing and processing operations to GDP and/or government revenue for some PICTs in the western part of the region (e.g. FSM, Palau, PNG and Solomon Islands).

It is also important to note that the potential opportunities for PICTs in the east arising from altered distributions of tuna due to climate change may be tempered, and the disadvantages for PICTs in the west reinforced, by (1) the prospect of increasing fuel prices; (2) the costs involved in upgrading fleets operating in subtropical areas to provide acceptable standards of safety at sea if cyclones become more severe (Australian Bureau of Meteorology and CSIRO 2011; Lough et al. 2011); and (3) the projected effects of sea-level rise and storm surge (Ganachaud et al. 2011) on shore-based facilities.

6.2 Food security

Although the projected decreases in demersal fish production due to climate change described in Section 5 are dramatic, the effects on the fish available per person are expected to be relatively limited in most PICTs. There are different reasons for this conclusion in each PICT, depending on the area of coral reef available per person to produce fish. Basically, PICTs fall into three groups with respect to reef area per capita (Bell et al. 2011b). In the first group (Cook Islands, Marshall Islands, New Caledonia, Palau, Pitcairn Islands and Tokelau), the area of coral reef per person, and low estimated population growth, is expected to yield an average of >300 kg of fish person per year for PICTs in Group 1 until the end of the century[2] (Bell et al. 2011b). The additional effects of the A2 emissions scenario are estimated to reduce the average production of demersal fish to >250 kg per person per year

[2] Average is based on fisheries production of 3 tonnes per km^2 of coral reef per year (Pratchett et al. 2011) but does not include estimates for Pitcairn Islands.

by 2100 for these PICTs, still leaving a large surplus of fish compared to the recommended 35 kg per person per year.

The second group of PICTs (FSM, French Polynesia, Kiribati, Niue, Tonga, Tuvalu and Wallis and Futuna) also has a relatively large average area of coral reef per capita. Taking the effects of population growth and climate change into account, the average availability of demersal fish per person is still expected to be >150 kg per year for this group of PICTs under the A2 scenario by 2100 (Bell et al. 2011b). However, distributing this production from remote reefs to population centres is likely to be a major factor limiting the availability of fish.

For the third group of PICTs (American Samoa, Fiji, Guam, Nauru, CNMI, PNG, Samoa, Solomon Islands and Vanuatu), there is a much lower ratio of coral reef habitat per capita (Bell et al. 2011b). Consequently, the gap between the sustainable harvests of demersal fish available from coral reefs and the recommended fish consumption of 35 kg per person per year is already wide and predicted to increase significantly due to the effects of population growth alone (Bell et al. 2011b). The gap is widened only slightly by the projected effects of climate change for most PICTs in Group 3, except Fiji and Solomon Islands (Bell et al. 2011b).

There are few implications for PICTs in Groups 1 and 2, except for the possible need to increase access to tuna near urban centres to prevent any shortages in fish due to localised overfishing of demersal fish and problems in delivering catch from remote reefs. However, the large projected shortfalls in the fish required for good nutrition of populations in PICTs in Group 3 have several profound implications. These implications centre around the need to provide access to the fish required for food security in the face of growing populations and climate change by (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 demersal fish harvests; (2) assessing how best to fill the gap with tuna (and partially by developing pond aquaculture in PICTs with adequate freshwater); (3) promoting the 'vehicles' needed to deliver the fish required; (4) allocating the appropriate proportion of the tuna catch to meet the needs for food security; and (5) including these allocations in the general tuna management framework of the Western and Central Pacific Fisheries Commission (Bell et al. 2011b).

The role of tuna in providing fish 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 (Bell et al. 2011b). PICTs in Group 3 will need to allocate an increasing proportion of their annual average tuna catches to national food security over time to provide the quantities of fish their populations need for good nutrition.

7 Adaptations

Because there are many more immediate factors affecting the sustainable management of oceanic fisheries than climate change, adaptations should address these other drivers in the short term and climate change in the longer term (Bell et al. 2011c; Grafton 2010), i.e. interventions should ideally be 'win-win' adaptations. However, adapting to climate change will also involve 'lose-win' adaptations–where the economic and social costs exceed the benefits in the short term, but where investments position PICTs to receive net benefits in the longer term. Below, we outline the main prospective win-win and lose-win adaptations needed to maintain or increase the contributions of oceanic fisheries in the tropical Pacific to economic development and food security. These adaptations are based on the assumption that regional stocks of tuna continue to be well managed. If this is not the case, the potential future benefits of win-win adaptations will not be realised.

7.1 Economic development

The adaptations and suggested policies to maximise the economic benefits from oceanic fisheries for PICTs in the central and eastern Pacific and minimise the impacts for PICTs in the west, based on the preliminary modelling (Lehodey et al. 2011), are outlined below. These adaptations involve (1) development of flexible management measures to allow fishing effort to shift east, while ensuring that large quantities of tuna can still be channelled through the established and proposed canneries in the west; and (2) optimising the productivity of tuna resources across the region.

7.1.1 Full implementation of sustainable fishing effort schemes (win-win)

The vessel day scheme (VDS) for the purse-seine fishery, which allocates fishing effort among the EEZs of the eight PNA countries based on agreed criteria (Aqorau 2009), provides an important means of accommodating the effects of ENSO events on redistribution of tuna, now and in the future. The VDS is intended to hold total fishing effort for PNA members constant, yet allow them to trade fishing days when the fish are concentrated either in the west or east. This effort management scheme ensures that all PNA members continue to receive some level of benefits, regardless of where tuna are concentrated. The built-in periodic adjustment of effort within the VDS should avoid the need for members further to the east to continually purchase vessel days from those in the west as tuna stocks move progressively east.

7.1.2 Diversify sources of fish for canneries (win-win)

Creating incentives for tuna caught in other EEZs to be landed in PNG and Solomon Islands may provide useful adaptations if more canneries are constructed there and lower tuna catches occur in the west. An Interim Economic Partnership Agreement (IEPA) with the EU is assisting PNG to develop its fish processing operations in the near term by paving the way for exports to Europe in the face of strong competition from canneries elsewhere. The 'global sourcing provision' of the IEPA is particularly advantageous because it enables PNG to obtain fish from vessels of different nationalities, including those operating outside its EEZ. Developing and maintaining a full economic partnership agreement with the EU in the long term is of great importance to PNG. It is also in the strong interest of Solomon Islands to make similar arrangements with the EU.

Other adaptations that may be needed to help maintain continuity in the supply of fish for canneries in PNG and Solomon Islands during El Niño episodes in the short term, and under the projected effects of climate change on tuna in the long term, include: (1) reducing access for DWFNs to their EEZs to provide more fish for national vessels; (2) requiring DWFNs operating within their EEZs to land a proportion of catches for processing by local canneries; (3) enhancing existing arrangements for their national fleets to fish in the EEZs of other PICTs; and (4) creating additional incentives for tuna caught in other EEZs to be landed in their ports.

7.1.3 Immediate conservation management measures for bigeye tuna (lose-win)

Addressing the current overfishing of bigeye tuna in the WCPO by reducing fishing mortality should help rebuild the population to a level that is expected to assist this species adapt to the projected changes to the tropical Pacific Ocean (Le Borgne et al. 2011, Lehodey et al. 2011). The benefits of management measures to reduce fishing mortality are not expected to be fully effective for 10–20 years because bigeye tuna is a relatively long-lived species (>12 years).

7.1.4 Energy efficiency programmes for industrial fleets (win-win)

Energy audits to identify how to reduce the use of fuel for routine fishing operations, followed by energy efficiency programmes to implement these savings, should increase the economic efficiency of fleets in both the near and long term. These initiatives should assist industrial fleets to cope with fluctuations in oil prices, lower CO_2 emissions and reduce the costs of fishing further afield for national vessels from FSM, PNG and Solomon Islands as the distribution of tuna shifts to the east.

7.2 Environmentally-friendly fishing operations (win-win)

Addressing any effects of existing tuna fishing operations, and those projected to occur as the distribution of tuna moves to the east, on non-target and dependent species should assist PICTs to meet the requirements of certification schemes to promote responsible fishing practices. Finding ways to reduce CO_2 emissions from commercial fishing fleets (outlined above), and from canneries, to ensure that tuna from the region is competitive in carbon labelling schemes should also help maintain access to markets for tuna as global pressure to minimise the carbon footprint of fishing and processing operations increases.

7.2.1 Safety at sea (win-win)

Although global climate models will continue to improve the weather forecasts available to industrial tuna fleets in the region, safety audits should be conducted to ensure that longline vessels, and any purse-seine vessels, operating within the cyclone belt can achieve acceptable standards for safety at sea if cyclones become more severe. This adaptation should help protect fishing crews both now and in the future.

7.2.2 Climate-proof infrastructure (lose-win)

New infrastructure built to support fishing fleets, canneries and loining plants should be constructed on land that will not be inundated by the sea-level rise projected to occur during the expected life-spans of such facilities (Ganachaud et al. 2011). At latitudes higher than ~10 °S to ~10 °N, infrastructure should also be built to withstand the possible effects of more severe cyclones and the associated storm surges. Investments may also be needed to modify existing infrastructure for industrial fishing operations and processing facilities.

7.3 Food security

The adaptations for maintaining the important role of fish for food security in the region centre mainly on (1) minimising and then filling the gap between the quantities of fish required for good nutrition and the fish available from coastal habitats due to population growth in the short term, and (2) addressing the added effects of climate change in the long term. These adaptations apply especially to the nine PICTs in Group 3, but should also assist the seven PICTs in Group 2 where problems may occur in distributing fish to urban centres. Although many of the necessary adaptations involve improving the management of coastal fish habitats and stocks and boosting pond aquaculture (Bell et al. 2011c), only the adaptations that apply to oceanic fisheries are outlined here.

7.3.1 Increase access to tuna for urban populations (win-win)

Promote better handling of small-sized tuna on board industrial vessels and the sale, storage and distribution of small-sized tuna and bycatch landed at Pacific ports. This adaptation should meet most of the shortfall in the fish needed for good nutrition for rapidly-growing urban populations in the region in the short and long term. It should also be favoured in PNG and Solomon Islands through regular landings of fish to supply canneries or for transhipping, and in Kiribati and Tuvalu by increased tuna catches there. However, care may be needed to release small tuna and bycatch purchased from industrial vessels onto the market in ways that do not undermine the livelihoods of local small-scale commercial fishers.

7.3.2 Increase access to tuna for coastal communities (win-win)

This can be done most effectively by installing networks of fish aggregating devices (FADs) anchored close enough to the coast to provide better access to skipjack and yellowfin tuna for subsistence and small-scale commercial fishers (SPC 2012). The technology for these anchored FADs has been refined over decades and works well, provided the FADs are placed where they attract mainly tuna and other oceanic fish, not pelagic fish closely associated with reefs. The value of tuna and other fish caught around anchored FADs greatly exceeds the costs of construction and deployment (Sharp 2011). However, to derive the full range of benefits many communities will need training in the methods used to fish around FADs, and in post-harvest processing of catches. Inshore anchored FADs should be seen as part of the national infrastructure for food security and replaced when they are lost due to wear and tear.

Transferring effort from coastal demersal stocks to nearshore pelagic species should deliver much of the fish required for food by coastal communities in the short and long term. Increased reliance on tuna by nearshore subsistence and artisanal fisheries should be favoured by climate change across the region until 2035, and in the east until 2100, due to projected changes in the distribution and abundance of tuna (Lehodey et al. 2011). Even in PNG and Solomon Islands, where tuna catches are eventually expected to diminish, tuna should still be plentiful enough to make FADs an efficient adaptation response to increasing human populations and declining demersal fisheries.

7.3.3 Develop coastal fisheries for small pelagic fish (win-win?)

The populations of small pelagic fish species that frequent coastal waters in the tropical Pacific (e.g. pilchards and scads) have potential to support greater fish catches in the short term. The outlook for the long term is uncertain—projected decreases in primary productivity due to increased stratification associated with higher sea surface temperature (Le Borgne et al. 2011) may cause abundance of small pelagic fish to decline. Conversely, projected increases of nutrients in coastal waters due to greater runoff (Lough et al. 2011), and changes in the positions of localised upwellings

(Ganachaud et al. 2011), may increase production of small pelagic fish in some locations in the long term.

8 Conclusions

Pacific Island countries and territories appear to be in a relatively good position to cope with the likely effects of climate change on oceanic fisheries. The projected changes in skipjack tuna catch will require more flexible approaches for supplying the existing and proposed canneries, and may eventually reduce GDP and/or government revenues slightly for some countries in the western Pacific. Even so, the expected effects of climate change on tuna across the entire region are among the better possible outcomes. In particular, PICTs with the highest dependence on tuna for government revenue (e.g. Kiribati, Tuvalu and Tokelau) are likely to receive greater benefits as tuna move east, whereas the projected decreases in production occur in those PICTs where industrial fishing and processing make only modest contributions to GDP and government revenue due to the relatively large size of their economies.

The robust tuna stocks of the region also provide PICTs facing a shortfall in the fish needed for food security with options to deliver access to the fish recommended for good nutrition as the projected production of coastal fisheries declines due to the direct and indirect effects of climate change. Even in PICTs in the west, where abundances of tuna are projected to decline progressively, there should still be ample tuna to use for national food security. The onus will be on these PICTs to allocate the required proportion of their average tuna catches for this purpose.

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