4. Gaps in knowledge

The vulnerability assessments summarised in Sections 2 and 6 were based on the best set of global climate models available when the assessment was prepared – the models used for the Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC-AR4) {Chapter 1}. However, much uncertainty still surrounds these assessments. This uncertainty is due to (1) the coarse grid sizes of these models and their inherent biases {Chapter 1}; and (2) gaps in the knowledge of the ecology of fish habitats and biology of harvested fish and shellfish.

The information needed to reduce uncertainty to progressively improve adaptations to climate change by the fisheries and aquaculture sector is outlined below.

4.1 Knowledge needed to improve the understanding of vulnerability

4.1.1 Surface climate and tropical Pacific Ocean

More long-term, high-quality data on surface weather are needed over a wider area of the region to (1) distinguish anthropogenic effects on surface climate from natural variability; (2) link local climate to larger-scale climate observations; and (3) validate and select the best-performing climate models for each region. Such data will also establish relationships between changes in rainfall and river flow on high islands.

Increased coverage and monitoring of ocean variables are also required. In particular, the vertical distribution of nutrients, oxygen and pH needs to be measured regularly over a much more representative area of the tropical Pacific Ocean to parameterise and validate models simulating the responses of the ocean to different emissions scenarios.

To improve the next generation of global climate models, significant biases in the CMIP3 models need to be addressed. These major biases include (1) the overly zonal orientation of the South Pacific Convergence Zone, which limits confidence in projections of the rainfall and wind fields of the central-southern Pacific; and (2) the warming associated with ENSO events, which is generally situated too far to the west and often occurs too frequently. A better understanding of the physical mechanisms driving these characteristics is needed to improve the parameterisation of coupled atmosphere-ocean models.

The resolution of global climate models also needs to be increased so that they 'see' PICTs. Dynamical and statistical techniques to downscale global climate models are available and under continuous development to enable projections to be made for smaller areas. However, considerable further effort is needed to determine how best to implement downscaling approaches to provide robust projections of changes to surface climate and the ocean at scales meaningful to management in PICTs. This work is now underway through Australia's Pacific Climate Change Science Programme[i].

4.1.2 Fish habitats

Open-ocean food webs

The extent to which climate change is likely to alter the availability of nutrients and oxygen that underpin food webs for tuna in the tropical Pacific Ocean, and the populations of phytoplankton, zooplankton and micronekton that comprise these food webs, is still poorly understood. Few reliable biogeochemical models can be linked to global climate models to project changes to these food webs and, apart from the Hawaii Ocean Time-Series station in the North Pacific Tropical Gyre {Chapter 4}, no long-term observations of nutrient and oxygen levels or the abundances of phytoplankton, zooplankton and micronekton exist in the region. More long-term time-series data are a priority. Better biogeochemical models will also pave the way for improved application of ecosystem models of upper trophic levels (e.g. SEAPODYM – Spatial Ecosystem and Population Dynamics Model, and Ecopath) to project the effects of changes in components of the food web on local abundances of tuna.

The research activities required to parameterise the biogeochemical models needed to improve our confidence in simulations of tuna catches under a changing climate are outlined below.

- Assess the effects of higher atmospheric concentrations of CO_2 on the carbon-to-nitrogen ratio of organic matter in the ocean through networks of *in situ* observations and laboratory experiments.
- Identify the spatial and temporal distribution of iron in the Equatorial Undercurrent, and the future bio-availability of different forms of iron, to determine whether the present limitations on production of phytoplankton in the nutrient-rich Pacific Equatorial Divergence Province (PEQD) {Chapter 4} are likely to continue.
- Describe the variability in abundance of micronekton, and factors driving this variability. This involves validating the acoustic methods used to assess micronekton by correlating the data with micronekton sampled using nets, and from the stomach contents of tuna and other top predators.

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

- Evaluate the extent of lateral transport of organisms from nutrient-rich oceanic provinces such as PEQD to nutrient-poor provinces, particularly within the aphotic zone.

Coral reefs

To reduce the uncertainty about how emissions of CO_2 and other greenhouse gases are likely to affect coral reefs {Chapter 5}, the following questions need to be answered.

- How are warming and acidification of the tropical Pacific Ocean affecting the early life history stages of corals and other key reef-building organisms? What are the knock-on effects of these processes on the wide range of species that comprise the food webs of the fish and invertebrates harvested from coral reefs?
- What is the effect of ocean acidification and warming on the relative balance between calcification and erosion? How would changes in this balance affect reef structure?
- Will synergies between projected increases in ocean acidity, SST and nutrient loads, and possibly more powerful waves from stronger tropical cyclones, damage coral reefs more severely?
- Which management strategies are likely to be most effective for coral reefs that have been bleached? Should closures to fishing and tourism be put in place until reefs have recovered?
- What are the likely consequences for coral reefs of a very rapid rise in sea level {Chapter 3}?
- Which coral reef habitats are likely to have the greatest natural resilience to bleaching, ocean acidification and other impacts of climate change?

Mangroves, seagrasses and intertidal flats

There are still major gaps in our knowledge of the distribution, diversity and coverage of mangrove and seagrass habitats, and the areas of intertidal flats, across the tropical Pacific {Chapter 6}. In many cases, even the existing estimates of habitat area are likely to be gross underestimates. In addition to providing estimates of habitat area for several PICTs, and checking the accuracy of estimates already made for PICTs, the following information is needed to improve our understanding of the vulnerability of these habitats and the roles they play in supporting coastal fisheries.

- Sensitivity of mangroves and seagrasses to sea-level rise and rates of sedimentation. Mapping deep meadows will help identify the seagrass habitats most at risk.
- The locations where mangrove and seagrass habitats are likely to have greater natural resilience to thermal stress, ocean acidification and the other projected impacts of climate change.

- The contributions of epifauna and infauna to the food webs of demersal fish and invertebrates associated with mangroves, seagrasses and intertidal flats, and the vulnerability of these food webs to the projected effects of climate change on these habitats {Chapter 6}.

Freshwater rivers and estuaries

Of all the fish habitats in the region, the least is known about freshwater rivers and estuaries {Chapter 7}. Ecosystem models for representative river types need to be developed and validated so that managers do not have to rely on information from other parts of the world. Important first steps are to quantify and map the habitats created by rivers and estuaries, and to set benchmarks for identifying changes in habitat area and quality. This basic research will also identify places where there is strong connectivity between habitats during the life cycles of migratory fish and invertebrate species {Chapter 10}. Information on the diversity, extent, function and connectivity of freshwater and estuarine habitats will help adjacent fishing communities to understand the contributions of these ecosystems to their food security and livelihoods.

4.1.3 Fish stocks

Oceanic fisheries

In addition to the need to downscale global climate models (Section 4.1.1), and parameterise biogeochemical models with better information on nutrients, iron and micronekton (Section 4.1.2), more knowledge about the biology of tuna is required to improve confidence in projected future catches simulated by the SEAPODYM model {Chapter 8}. The main gaps in knowledge to be filled are listed below.

- Identify the likely responses of skipjack, yellowfin, bigeye and albacore tuna to variation in key environmental variables, including:
  - optimal temperature and dissolved oxygen ranges and thresholds for different life history stages;
  - potential effects of increased ocean acidification on production of gametes, fertilisation, embryonic development, hatching, larval behaviour and feeding ecology (restricted to yellowfin tuna in the first instance because this is the only species of tropical tuna propagated in captivity);
  - interactions among the effects due to temperature and ocean acidification; and
  - possible changes in vertical distribution of each species of tuna due to variation in temperature and dissolved oxygen, and the consequences for their vulnerability to capture by different gear types.
- Assess the carrying capacity of the pelagic ecosystem for tuna in the tropical Pacific, and whether the productivity of stocks is controlled directly by food

abundance, or by non-linear relationships such as variation in food assimilation rates with changes in prey density. These tasks require a good understanding of:

- energy transfer efficiency between all levels of the food web, but especially from the lower levels to the mid-trophic level (micronekton);
- spatial and temporal variation in diversity, distribution and abundance of micronekton across the region;
- diets of the four species of tuna, and the scope for competition between the species; and
- nutrient-rich coastal waters as feeding areas for tuna, and the possible retention of tuna in such areas – the archipelagic waters under the influence of increased runoff from the Sepik-Ramu river system in PNG are of particular interest {Chapter 8}.

Coastal fisheries

A better understanding of the likely effects of climate change on the production of coastal fisheries depends on identifying the responses of key fish and invertebrate species to projected alterations in environmental conditions and habitats. The main research activities involved are listed below.

- ➢ Assess the role of coral reefs, and variation in their structural complexity and biological diversity, in determining the distribution and abundance of associated fish and invertebrate species, especially during larval settlement and recruitment. This research is closely linked to assessing the comparative resilience of different reef-building corals (Section 4.1.2).
- ➢ Investigate the role of mangroves, seagrasses and intertidal flats in supporting demersal fish and invertebrates, particularly their importance as nursery and feeding areas, and their links with coral reefs. We also need to know whether fish and invertebrates use these habitats sequentially as they grow, and whether the juxtaposition of habitats within the mosaics they form affects fisheries production.
- ➢ Assess the sensitivity and adaptive capacity of key demersal fish species and invertebrates to changes in SST and pH, including (1) the effects on early life history stages; and (2) the combined effects of these variables and their interactions with other anthropogenic stressors.
- ➢ Model the effects on larval dispersal of decreases in the strength of the South Equatorial Current and the South Equatorial Counter Current {Chapter 3}.
- ➢ Determine whether a link exists between the risk of ciguatera fish poisoning and climate change. In particular, whether populations of the toxic microalgae *Gambierdiscus* spp. are affected by the deterioration of coral reefs, and whether the projected changes in SST are likely to alter the distribution, occurrence and virulence of ciguatera.

- Estimate the risks of any alteration in the incidence of other harmful marine algae caused by climate change to coastal fisheries and communities that rely on coastal fish for food.
- Evaluate the likely effects of higher levels of nutrients from the projected increases in runoff around high islands in tropical Melanesia on the productivity of small pelagic fish species.
- Assess the vulnerability to climate change of deepwater demersal species taken by coastal fisheries, especially snappers and groupers.

Freshwater and estuarine fisheries

To increase confidence in the vulnerability of these poorly understood fisheries, basic research is needed on the biology of the main species, particularly the way they use various habitats at different stages of their life cycles, and their responses to changes in habitat availability and quality. It is also important to understand interactions among fish species (including introduced and invasive species) and to determine whether such interactions are likely to be affected by the projected changes to water temperature and flow rates {Chapter 10}. Research on fish and invertebrates that are exposed to a wider range of climate change effects because they migrate between freshwater and the sea is a priority.

4.1.4 Aquaculture

Pond aquaculture

In addition to any modifications needed to adapt the well-established methods for pond aquaculture for the region {Chapter 11}, other research activities are required to (1) assist PICTs to evaluate whether pond aquaculture is likely to be enhanced as a result of climate change; and (2) identify any possible disadvantages of pond aquaculture as a way of increasing access to fish. These research activities are outlined below.

- Couple global climate models to the level of river catchments so that planners, managers and stakeholders can combine this information with geographic information system (GIS) data to identify areas most likely to be suitable for pond aquaculture in the future.
- Evaluate any potential impacts of Nile tilapia introduced for pond aquaculture on freshwater biodiversity. This research needs to be designed to ensure that any effects of escaped fish on biodiversity are not confounded with alterations to freshwater habitats caused by poor management of catchments {Chapter 7}. Because Mozambique tilapia are well established throughout the region, it will also be important to determine whether Nile tilapia that escape from ponds are likely to have any impact on biodiversity over and above any effects attributed to Mozambique tilapia.

- Identify the likelihood that warmer and wetter conditions may increase the risks posed to pond aquaculture by disease {Chapter 11}.
- Assess whether freshwater aquaculture ponds increase habitat for malaria mosquitoes (*Anopheles* spp.) and, if so, identify how ponds could be managed to reduce the risk.

Commodities for livelihoods

Research is needed to determine whether coastal habitats in the tropical Pacific will continue to be suitable for the production of aquaculture commodities for livelihoods in the face of climate change. The main research tasks are summarised below.

- Assess whether the temperature fluctuations during the short 'spring' and 'autumn' seasons in New Caledonia that cause mortality of shrimp are likely to be reduced or accentuated in the future.
- Evaluate the scope for extending seaweed farming to Vanuatu as temperatures warm. If it is considered technically feasible, gender-based, socio-economic research will be needed to determine whether the relatively low incomes involved are likely to (1) meet the expectations of coastal communities; and (2) result in sufficient production to warrant establishment of enterprises to export the products.
- Determine the likely effects of ocean acidification on (1) survival of pearl oysters and formation of high-quality pearls; (2) recruitment of milkfish postlarvae used to stock ponds; and (3) fitness of sea cucumbers released in sea ranching projects, due to effects on the size and strength of spicules. If acidification has significant effects on pearl quality, research will be needed to identify whether microsites exist where the buffering effects of nearby coral reefs, macroalgae and seagrasses {Chapters 5 and 6} maintain aragonite saturation levels within the limits required by pearl oysters to produce high-quality nacre.
- Ascertain whether pathogens affecting the pearl and shrimp industries are likely to become more virulent with increasing water temperatures.

4.2 Knowledge needed to implement adaptations effectively

4.2.1 Economic analysis

The rich tuna resources of the region provide PICTs with many potential adaptations to maintain the benefits of fisheries for food security and livelihoods (Section 3.4), even under the projected redistribution of tuna to the east {Chapter 12}. It is already evident that 'domesticating' the tuna industry to create jobs on fishing vessels and in processing operations adds much value to local economies compared with selling access rights to DWFNs {Chapter 12}. However, economic analysis is needed to determine the relative benefits of allocating a proportion of estimated sustainable tuna catch to subsistence and small-scale commercial fishers, compared with allocating it all to DWFNs or domesticating the industry. In particular, governments need to know how the social (health) and economic benefits people receive from catching and eating fresh tuna, or selling it at a local market, compare with the benefits people receive via national revenue from licence fees, or from jobs in the tuna industry.

Provided such analyses encompasses the effects of population growth on local demand for fish, and the effects of climate change on the projected availability of tuna, they should (1) aid PICTs to optimise future benefits from their tuna resources, and (2) identify the best ways to provide access to the fish (or other animal protein) needed for food security {Chapter 12}. The results are expected to differ among PICTs, depending on the estimated sustainable catches of tuna from their EEZs, the size of their populations, their capacity to domesticate fishing and processing operations, and the availability of other opportunities for people to earn income.

4.2.2 Social dimensions

Considerable gaps in knowledge still exist about how Pacific communities are likely to embrace the recommended adaptations and the need for change. Learning to catch or produce fish in new ways, and to eat different types of fish, are important adjustments for communities to make in preparation for the times ahead. Research is needed to gauge the willingness of people to make these changes, and how to assist them where necessary. The traditional social mechanisms used by Pacific people to respond to extreme events, such as tropical cyclones and droughts (Section 13.4), should predispose them to make a smooth transition to the recommended adaptations. But such responses should not be assumed. The suitability of these traditions for the projected changes in the production of fisheries and aquaculture under the A2 emissions scenario needs to be examined.