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Effects of Climate Change on Ocean Fisheries Relevant to the Pacific Islands

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EXECUTIVE SUMMARY

In the Pacific Island region, oceanic fisheries target four species of tuna – skipjack, yellowfin, bigeye and South Pacific albacore – and make critical contributions to economic development, government revenue and livelihoods in most nations. Climate change is expected to have profound effects on oceanic fish habitats, food webs, the fish stocks they support and, as a consequence, the productivity of fisheries. The four main tuna species are expected to respond directly to changes in water temperature, oxygen, ocean currents, stratification of the water column and the location of the Western Pacific Warm Pool (warm pool), and indirectly to changes in the structure of food webs (Lehodey *et al*. 2010a, 2011, Bromhead *et al*. 2015; see Fish, Shellfish and Coastal Fisheries paper, this volume). Some of the other oceanic fish species which are caught as bycatch by longline tuna vessels have a greater association with coastal habitats (e.g. wahoo) and are also likely to be impacted by the effects of changes to coral reefs and nutrient supplies on their prey. Based on recent distribution modelling, tuna populations are expected to move eastward and to higher latitudes due to climate drivers, which will present the greatest challenge for national economies and livelihoods in the western Pacific. The redistribution of tropical tuna species will benefit mostly Cook Islands, French Polynesia, Fiji and Vanuatu, which are likely to have future opportunities for greater engagement in supply chains. However, the progressive eastward shift in skipjack tuna is likely to have negative effects on the contributions of tuna fishing to government revenue and tuna processing to GDP for other nations in the western Pacific (e.g. Papua New Guinea, Solomon Islands).

What is Already Happening?

Four species of tuna are critically important for many Pacific Island countries and territories (PICTs) due to the fact that their exclusive economic zones (EEZs) are prime fishing grounds for the abundant skipjack tuna (*Katsuwonus pelamis*), and for yellowfin (*Thunnus albacares*), bigeye (*Thunnus obesus*) and South Pacific albacore (*Thunnus alalunga* (hereafter albacore) (Harley *et al*. 2014). The combined harvest of these four tuna species from the EEZs of PICTs totalled more than 1.5 million tonnes in 2016, representing ~30% of the global tuna catch.

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The rich tuna resources of the region contribute to the economies of PICTs mostly through the sale of access fees to vessels from distant water fishing nations (DWFN), particularly Japan, USA, China, Chinese Taipei, Korea and Spain. These access fees make significant contributions to government revenue. For example, in 2013/2014, seven PICTs received 10-84% of their government revenue from these access fees and associated licences. In some PICTs, such as American Samoa, Fiji, Papua New Guinea (PNG) and Solomon Islands, onshore processing of tuna contributes significantly to employment and GDP (Bell *et al*. 2011a). More than 23,000 jobs have been created through tuna processing operations in American Samoa, Fiji, Marshall Islands, PNG and Solomon Islands, as crew on foreign and local fishing vessels, and through observer programmes to monitor compliance in the tuna purse-seine fishery (Pacific Islands Forum Fisheries Agency) (FFA 2016).

The distribution and abundance of tuna stocks are influenced by natural climate variability, such as the El Niño Southern Oscillation (ENSO), at inter-annual scales, and the Pacific Decadal Oscillation (PDO) at decadal scales. The influence of such climate variability can impact the survival of larvae and thus subsequent recruitment, and also redistribution of the most suitable habitats for tuna species. This influence is detected more easily for skipjack due to its shorter lifespan. Other tuna species have longer life spans and integrate environmental variability over more age classes, thus making it more difficult to isolate the effect of climate variability from other sources of variability.

The stock status for the four species of tropical tuna caught in the EEZs of PICT are assessed regularly by the Oceanic Fisheries Programme at the Pacific Community (SPC) on behalf of the Western and Central Pacific Fisheries Commission (WCPFC). Bigeye and yellowfin tuna stocks were assessed in 2017, skipjack tuna in 2016 and albacore in 2015 (Brouwer *et al*. 2017). In all cases except albacore which is assessed in the area south of the equator, the assessments are made for the entire distribution of each stock within the Western and Central Pacific Ocean (WCPO). The fisheries convention area for the WCPO includes the EEZs of PICTs, the EEZs for Indonesia and the Philippines, and high seas areas. The annual catches of all four tuna species in this convention area since 1960 are shown in Figure 1. The assessments are considered a good measure of the status of stocks in all EEZs because more than 50% of the total tuna catch from the WCPO is made in the EEZs. While fishing strongly impacts all tuna stocks, bigeye and yellowfin tuna are the most heavily exploited stocks by both surface and subsurface fishing gears. The most recent skipjack stock assessment indicates that longline fishing mortality has increased over time. However, even the current fishing mortality rates are estimated to be about only 0.45 times the level of fishing mortality associated with maximum sustainable yield (MSY). Overfishing is not occurring. For the abundant skipjack tuna, current recruitment is estimated to be increasing and biomass is estimated to be at 58% of the level predicted in the absence of fishing (Brouwer *et al*. 2017). In 2016, 1,075,620 Mt of skipjack tuna were caught in the EEZs of PICTs, which represented 70% of the total tuna catch taken from the waters of PICTs.

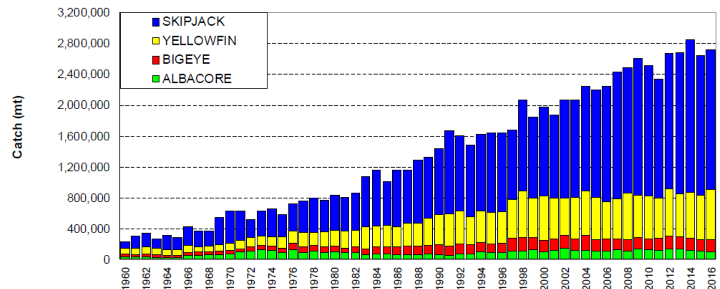


Figure 1. Catch (mt) of South Pacific albacore, and bigeye, skipjack and yellowfin tuna, in the entire Western and Central Pacific Convention Area (Williams *et al*. 2017).

For yellowfin tuna, fishing mortality on both adults and juvenile fish has increased in recent years but remains mostly below the level of fishing mortality associated with MSY. Spawning biomass of yellowfin tuna continues to decline slowly but is estimated to still be above the limit reference point of 20% of the level prior to fishing (WCPFC 2017). In 2016, 346,502 Mt of yellowfin were caught in the EEZs of PICTs, which represented 23% of the total tuna catch taken from these waters.

The 2017 assessment of bigeye tuna in the WCPO indicates that the status of the species is more robust than previously estimated (WCPFC 2017). In previous assessments, the spawning biomass was estimated to be below the 20% limit reference point. However, new information on the growth of bigeye tuna, plus a decade of active management to rebuild the population, now suggests that spawning biomass may currently be ~30% of original spawning biomass. In 2016, 59,662 Mt of bigeye were caught in the EEZs of PICTs, which represented 4% of the total tuna catch taken from the waters of PICTs.

For albacore, the most recent assessment indicates that although fishing mortality has generally been increasing over time, it remains well below the fishing mortality that will support MSY. Spawning biomass is estimated to be above the limit reference point of 20% of the level prior to fishing. An index of economic conditions in the albacore fishery, which integrates fishing costs, catch rates and fish prices, indicates that there has been a decline in profitability of longline fishing over time, reaching an historical low in 2013. Domestic vessels from some longline fleets have reduced their fishing effort in response to these conditions. In 2016, albacore represented ~1% of the total tuna catch taken from the waters of PICTs.

Since the largest catches of skipjack tuna are made in equatorial waters where tropical cyclones do not occur, there have been few (if any) reports of damage to purse-seine vessels from storms. Much of the longline fishing for albacore occurs in subtropical waters prone to cyclones. However, good regional weather forecasts enable longline vessels to seek shelter when extreme events are predicted. Tropical cyclones do cause problems for coastal communities using nearshore, anchored fish aggregating devices (FADs) to catch oceanic fish species, for example, Tropical Cyclone Pam destroyed many such FADs in Vanuatu in 2015 (Bell *et al*. 2018).

What Could Happen?

Climate change is projected to have profound effects on the physical environment in the tropical Pacific Ocean. Average sea surface temperature (SST) in the Western Pacific Warm Pool (hereafter 'warm pool') has increased by ~0.7 °C since 1900 (Bindoff *et al*. 2007, Cravatte *et al*. 2009) and is expected to continue rising by 1.2–1.6 °C by 2050 and 2.2–2.7 °C by 2100, relative to 1980-1999, under a high emissions scenario (Ganachaud *et al*. 2011). The size of the warm pool is also projected to increase, although there is considerable uncertainty about how the dynamics of the warm pool will change (Brown *et al*. 2014). Models also project a decrease in oxygen (O_2) concentration by 2100 in surface waters. In subsurface waters, the increased temperature and stratification of the ocean at higher latitudes are expected to lead to a decrease in O_2 transfer from the atmosphere due to reduced ventilation and advection, resulting in lower O_2 concentrations in the thermocline (Ganachaud *et al*. 2011).

Changes in ocean circulation are also projected and are expected to alter the timing, location, and extent of the upwelling processes on which most oceanic primary productivity depends. Changes in the vertical structure of the water masses and in the depth and strength of the thermocline will also impact the availability of nutrients. The production of phytoplankton at the base of the food web supporting tuna is primarily constrained by the availability of nutrients, such as nitrogen, and/or micro-nutrients, such as iron. Because phytoplankton rapidly exhaust the limited nutrients of surface waters, substantial primary production occurs only where deep, nutrient-rich waters are brought to the surface by upwelling and eddies, or when the thermocline becomes shallower and/or weaker allowing the diffusion of nutrients from the deep nutrient-rich water masses towards the surface (Le Borgne *et al*. 2011).

Based on one climate model (IPSL-CM4) under a high emissions scenario, Le Borgne *et al*. (2011) project a 9% decrease in phytoplankton abundance in the warm pool by 2100 and a 20% to 33% decrease in area of the archipelagic deep basin ecological province in the southwest of the region (Figure 2). Zooplankton abundance is also projected to decrease in these regions due to a decline in localised upwelling systems in the tropical Pacific that will likely lead to reduced primary productivity with a cascading effect on higher trophic levels.

The dynamic relationship between tuna and their environment, combined with their life history characteristics, results in complex interactions, feedback loops and non-linear effects. This complexity has been modelled by the dynamic Spatial Ecosystem and Populations Dynamics Model (SEAPODYM) (Lehodey *et al*. 2008, Senina *et al*. 2008) and Apex Predator Ecosystem Model Estimation (APECOSM-E) model (Dueri *et al*. 2012) that simultaneously evaluate interactions between environmental changes, biological function and spatial dynamics of tuna populations.

Preliminary simulations of climate change impact on albacore (Lehodey *et al*. 2015), skipjack tuna (Lehodey *et al*. 2013a, Dueri *et al*. 2014, Matear *et al*. 2015, Senina *et al*. 2016), bigeye tuna (Lehodey *et al*. 2010b, 2013b) and yellowfin tuna (Senina *et al*. 2015, Lehodey *et al*. 2017) use outputs from global coarse-resolution Earth Climate models. They point to declining abundances in the western Pacific Ocean and/or distribution shifts towards the eastern Pacific (Figure 3). These changes are driven largely by the projected, less favourable spawning grounds associated with the weakening of equatorial upwelling and current systems, and the warming of waters and associated increase of water stratification in the western region leading to lower primary production (Steinacher *et al*. 2010, Bopp *et al*. 2013).

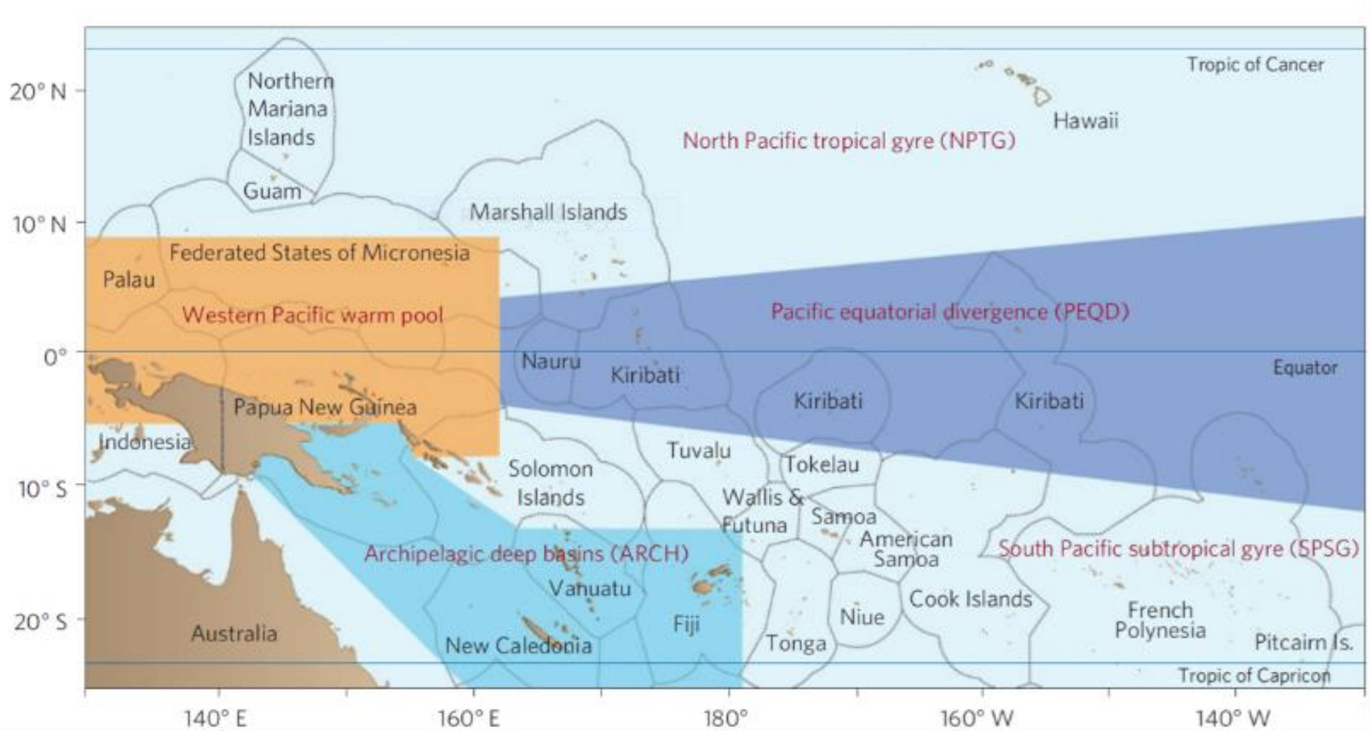


Figure 2. Map of the tropical Pacific Island region showing the five ecological provinces and Pacific Island countries and territories (source: Bell *et al*. (2013) and the Pacific Community, New Caledonia).

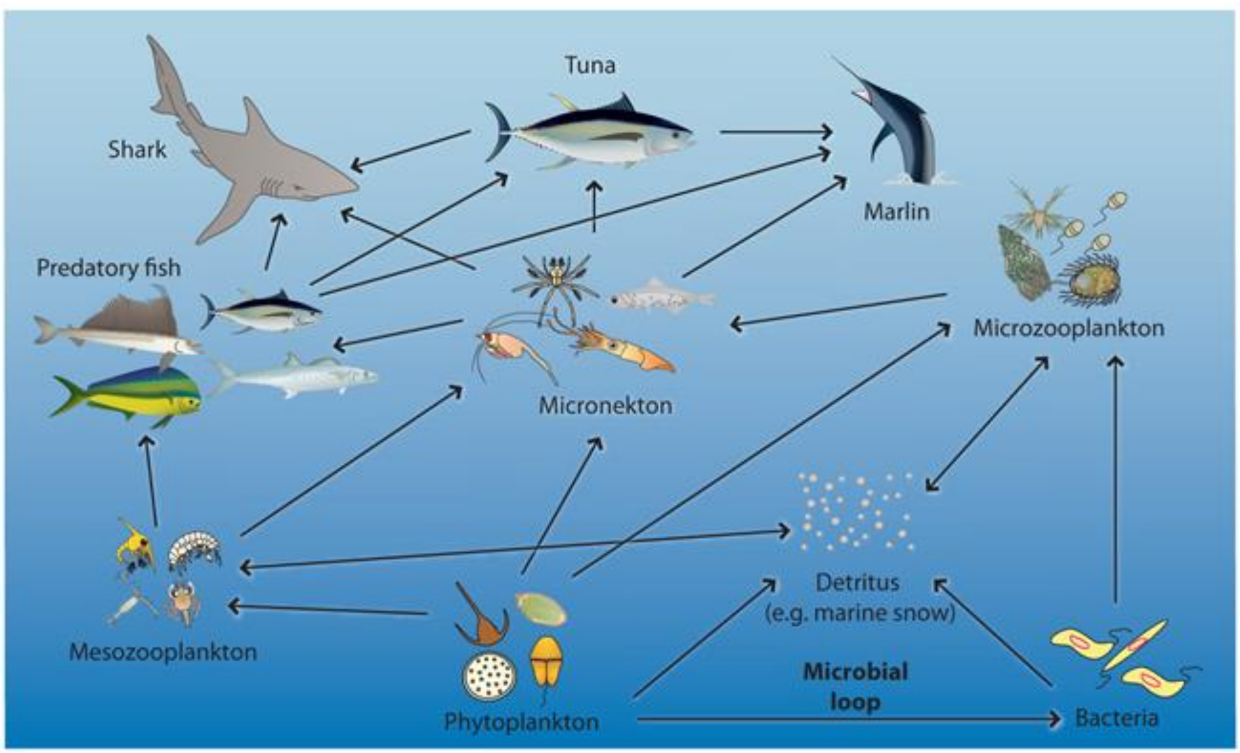


Figure 3. Projected distributions of: (A) skipjack tuna (*Katsuwonus pelamis)*, (B) yellowfin tuna (*Thunnus albacares)*, (C) bigeye tuna (*Thunnus obesus*), and (D) South Pacific albacore tuna (*Thunnus alalunga)* biomass across the tropical Pacific Ocean under a high emissions scenario; simulations for 2005 and projections for 2050 and 2100 are derived from SEAPODYM, including projected average percentage changes for the outlined areas east and west of 170 E (source: Lehodey *et al*. 2013a, 2013b, 2015; Senina *et al*. 2015).

Tuna populations are also thought to be especially sensitive to changes in the productivity of food web which supports them (Figure 4), ranging from changes in primary productivity to the abundance of their micronekton prey (Lehodey *et al*. 2011). In particular, decreases in micronekton are likely to increase natural mortality of tuna and lower the overall production of tuna fisheries in the region. Therefore, improved prediction of changes in ocean productivity under climate change is particularly important. Interestingly, climate change simulations at higher resolution indicate enhanced vertical shear mixing and increased vertical supply of nutrients to the photic zone in the warm pool, and thus primary production. Any such change in primary productivity in the western tropical Pacific is expected to benefit mainly skipjack tuna habitat (Matear *et al*. 2015).

The projected changes in vertical and horizontal distribution of tuna are likely to have consequences for fishing operations. Changes in the location of prime fishing grounds and the catchability of tuna by surface and longline fisheries are expected to affect the sector in a similar way to that observed during El Niño events. In particular, fishing grounds are likely to be displaced further eastward along the equator and at higher latitudes, increasing access to tuna resources in international waters (Lehodey *et al*. 2011, 2012, 2013b, Bell *et al*. 2013).

Regardless of where fishing is concentrated, increased stratification could enhance catch rates of the surface-dwelling skipjack and yellowfin tuna where SST remains within their preferred ranges. The effects of the shoaling of the thermocline in the western Pacific during El Niño events on catches of yellowfin tuna provides an analogy – such shallowing results in higher catch rates by the surface fishery in the warm pool due to the contraction in the vertical habitat for this species (Lehodey 2000). Changes in O_2 are also likely to constrain yellowfin tuna to the surface layer, which would make them more vulnerable to capture by the surface fishery (Lehodey *et al*. 2011).

SEAPODYM simulations on the future distribution of albacore are highly dependent upon changes in O_2, for which there is still uncertainty. Current projections under the “business as usual” IPCC scenario for this stock suggest a decrease in abundance until 2035, then a stabilization and a reversed trend after 2080, coinciding with the emergence of a new spawning ground in the north Tasman Sea (Lehodey *et al*. 2015).

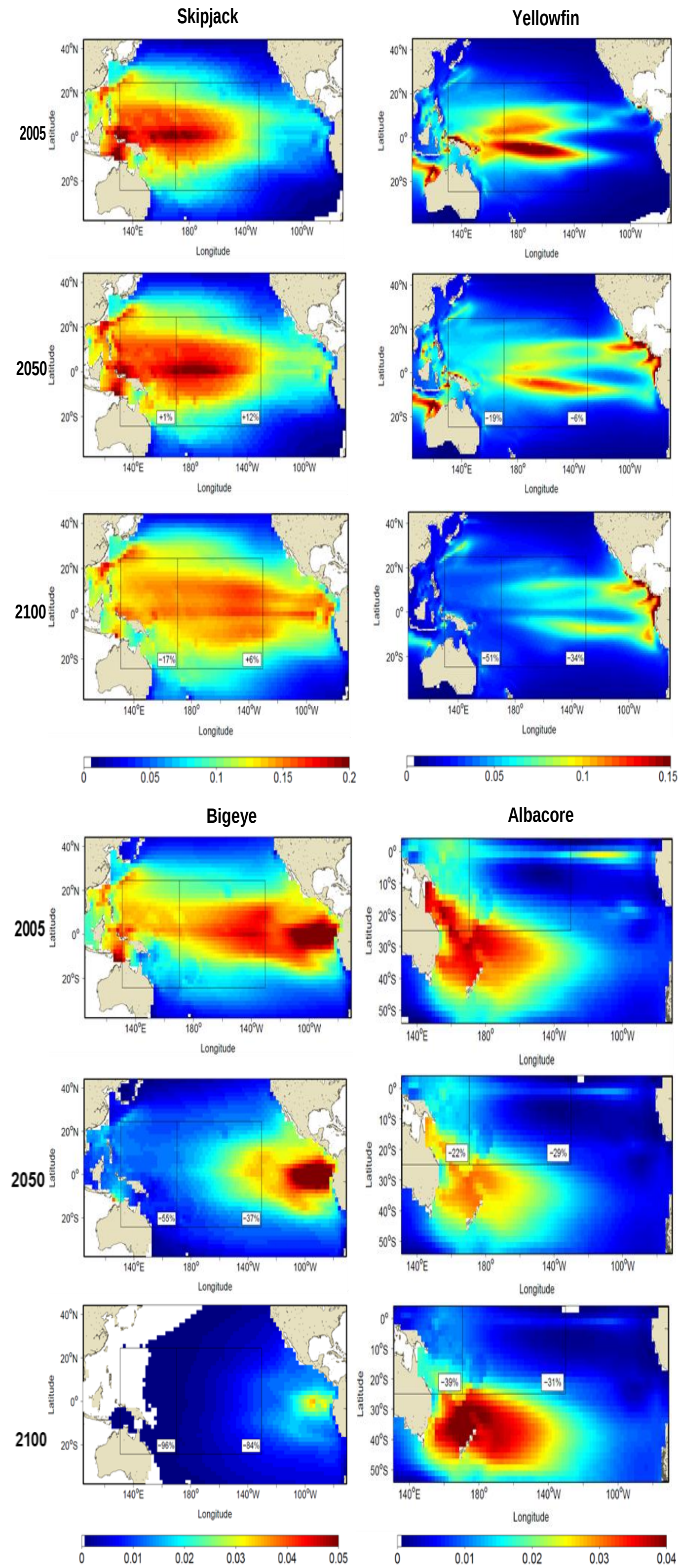


Figure 4. Oceanic food web supporting all species of tuna and other large pelagic fish (source: Le Borgne *et al*. (2011) and the Pacific Community, New Caledonia).

The projected changes in temperature and primary productivity are projected to mainly affect where tropical tuna species spawn. In particular, the spawning areas of skipjack, yellowfin and bigeye tuna are projected to shift to the central and eastern equatorial region. Productivity is projected to remain relatively high in a temperature range favourable for spawning in this general area and could also extend into the Tasman Sea where the subtropical albacore occurs (Lehodey *et al*. 2015).

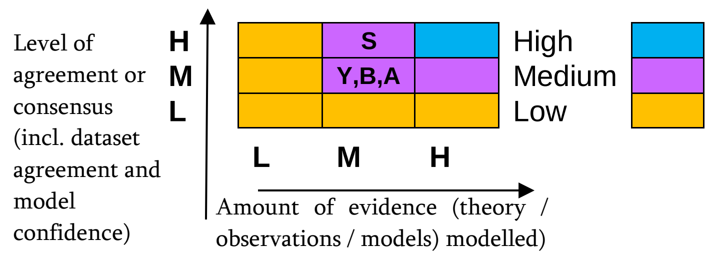
Economic development and government revenue
Based on the available modelling for the four species of tuna, which projects increases in abundance in the central-east and decreases in the west, the progressive redistribution of tuna could confer advantages to PICTs in the eastern part of the WCPO if average levels of effort increase in their EEZs. The modelling suggests that the total catch, essentially driven by the skipjack fishery, will be maintained until 2050, even under a high emissions scenario, and will decrease later in the century. These benefits will depend on the Parties to the Nauru Agreement (PNA) members[1] and industrial fleets complying fully with the vessel days scheme (VDS) and with the target reference points for catches of yellowfin, bigeye tuna and albacore that are still to be agreed by Western and Central Pacific Fisheries Commission (WCPFC). The VDS already has mechanisms to cater for changing stock distribution that would likely need to be enhanced/reconsidered under the long-term shifts in biomass forecast to be driven by climate change. They will also depend on PNA members continuing to develop more flexible management systems to cope with the changing spatial distribution of tuna stocks and fishing effort.

Potential disadvantages may arise if the progressive movement of tuna to the east affects the contribution of fishing and processing operations to GDP and government revenue for countries in the west of the region, particularly PNG, Solomon Islands and the Federated States of Micronesia (FSM). For example, plans to expand industrial fishing and processing (canneries) in PNG and Solomon Islands to localize more of the benefits from tuna resources under the Regional Roadmap for Sustainable Pacific Fisheries could be affected. Overall, however, the effects of any decline in industrial fishing and processing due to climate change on the GDP of PNG and Solomon Islands are expected to be limited because these activities make relatively small contributions in percentage terms to the national economies of both countries (Bell *et al*. 2011b). Other issues are that an increasing shift of tuna resources towards international waters of the central-eastern Pacific Ocean will make monitoring and management regulations more difficult to impose, and total tuna business opportunities are expected to be reduced in the second half of the century if projected lower primary productivity eventuates.

The modifications to vessels to reduce fuel costs identified during the energy audits of industrial fishing vessels by FFA, should assist national fleets having to travel greater distances to catch fish in the future.

Confidence Assessment

What is already happening
S=skipjack; Y=yellowfin; B=bigeye; A=albacore



There is substantial current information for skipjack tuna, including: tagging, catch, effort and biological data which are collected in a consistent manner. The modelling of skipjack tuna distribution is influenced by water temperature, which is well-fitted, and the models can replicate observations in describing the impact of ENSO on skipjack tuna distributions.

For bigeye, yellowfin tuna and albacore, there is a degree of conflict in the current data sources and therefore less certainty in the estimate of parameters. Trophic dynamics are more complex, and their influence on distribution is not well understood.

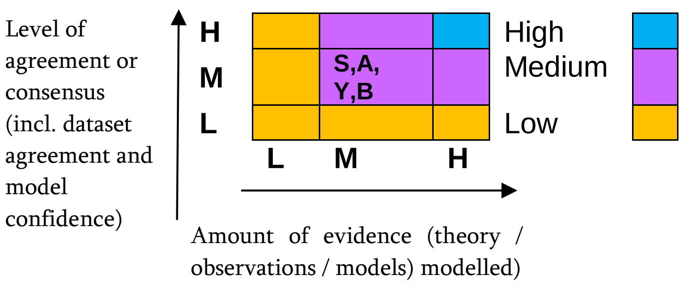
For all four tuna species, there is relatively good agreement on the level of exploitation (intense but not overfished) of stocks, and that the impacts of fishing on stocks are stronger than the effects of natural climate variability. Observations input to models and theory provide consensus on the sensitivity of tuna to key oceanic variables (e.g. temperature, O_2, primary production), except for pH, where there is limited information on sensitivities and responses of tuna

[1] PNA members include: Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, PNG, Solomon Islands and Tuvalu.

(Bromhead *et al*. 2015, Frommel *et al*. 2016, Lehodey *et al*. 2017).

Both theory and some observations show a consistent impact of ENSO on tuna catchability for all species, however, there is limited evidence (models) suggesting tuna recruitment is correlated with climate variability (either ENSO or PDO), although skipjack spawning is clearly correlated to temperature, and El Niño events seem to provide better conditions for recruitment (e.g. Lehodey *et al*. 2006).

What could happen in the future
S=skipjack; Y=yellowfin; B=bigeye; A=albacore



The same issue exists for bigeye, yellowfin and albacore, where there is a degree of conflict in the data sources, and therefore less certainty in future projections. The medium assessment for all species is based on some areas where there is consensus or good information (+) and areas where there are uncertainties (-):
+ Fishing exploitation level will remain high;
+ Similarities between climate change influence and El Niño events;
+ Clear impact of El Niño events on skipjack tuna distribution;
+ Mechanistic tuna models available that include key oceanic drivers;
- Limited number of stock models and studies available for future projections;
- Uncertainty in the projected trends in key oceanic variables for tuna (temperature, dissolved oxygen, primary production, currents) by Earth Climate models;
- Contradictory trends in primary production in the warm pool simulated with higher resolution;
- Uncertainty on the adaptive capacity (genetic flexibility) of tuna species to warmer waters;
- Uncertainty on the biomass of micronekton and level of coupling/decoupling between upper- and mid-trophic levels.

Knowledge Gaps

1) Improved physical and biogeochemical forcings:

The most advanced modelling framework for investigating climate change impacts on Pacific tuna populations and fisheries is SEAPODYM. To achieve new progress with this model, and others, the physical and biogeochemical forcings provided by Earth Climate models need to be carefully corrected from their biases. Many published studies on the impact of climate change on marine resources and biodiversity use projections of physical and biogeochemical forcings without any bias corrections. This can lead to spurious correlations when estimating habitat parameters with observations collected over the historical period. Improved forcings from Earth Climate models with higher resolution (1/4°) also need to be used because they could make substantial improvements to predictions (Matear *et al*. 2015). While the need to increase model resolution is acknowledged by researchers working on biogeochemistry and biology, it is not a priority in the Earth Climate Modelling community, due to the very high computational costs. A methodology needs to be developed to offer climate change scenario simulations at higher resolution for investigating the impact on marine resources and biodiversity, for example, with off-line coupling and downscaling techniques from coarse resolution atmospheric forcings. It is critical to confirm whether primary production is predicted to decrease in the warm pool when modelling at higher resolutions, and what the consequences are on the food web and tuna dynamics.

2) Improved knowledge and models for ecosystem and tuna:

Optimal parameterization of SEAPODYM over an historical fishing period can be improved with additional data, both for the mid-trophic level (micronekton) and tuna populations, e.g., with bio-acoustic and tagging data. More realistic estimates of future fishing effort and catch of the four species of tuna under climate change and various socio-economical scenarios can be predicted by developing and coupling a fishing fleet dynamics model. Further data on the economic impacts of oceanic fisheries distributional shifts and alternative management paradigms on national economies is needed to parameterize such models and to inform decision-making. Further mechanisms may be included in the model(s) to simulate climate change impacts associated with ocean acidification, and the combination of changes in temperature, O_2 concentration and pH, particularly on growth, recruitment and distribution. They should rely on new knowledge produced in laboratory experiments and evaluate the genetic flexibility of tuna to changing environmental variables.

The rapid progress in genetic technologies provides also greater power to detect differences in the spatial structure of stocks. Recent and preliminary genetic analyses of the population structure of yellowfin tuna indicate heterogeneous population structure between the western Pacific (Australia) and central Pacific (Tokelau) (Grewe *et al*. 2015). Similarly, analysis of conventional tagging data indicates that there could be separate stocks of bigeye tuna across the tropical Pacific Ocean (Schaefer *et al*. 2015). The finer-scale understanding of tuna stock structure will improve stock assessment and enable regional fisheries managers to identify which countries share each stock, and how much of each stock occurs in high seas areas. Moreover, once the spatial stock structure of each tuna species has been identified, it will be possible to model the response of each separate tuna stock to climate change and ocean acidification, and the adaptive potential of those stocks.

3) Ensemble simulations (forcings and models):

There is good agreement in the climate modelling community about the need to use ensemble simulations instead of a single simulation to account for uncertainty in the models and forcings. This approach should be extended to SEAPODYM and other models proposed to project the future of marine species population dynamics, abundance, habitat or "ecological niche". To provide confidence in forecasting, results should be evaluated for the historical period including observed natural variability during ENSO phases, using large fisheries-dependent datasets and new detailed observations collected to validate the model.

Importantly, once there is a greater understanding of climate change implications for tuna biology and stocks, there should be an evaluation of what management regimes (at which spatial scales) might be more robust to the projected climate change effects and how current management will perform.

Socio-economic Impacts

Decisions about the most appropriate options for PICTs to adapt to the effects of climate change must take into account the many other drivers that affect the ability of fisheries to support economic development, food security and livelihoods (Gillett and Cartwright 2010). Human population growth and increasing demand for fisheries resources globally represent just some of these drivers.

The adaptations to maximise the economic benefits from tuna for PICTs in the central and eastern Pacific Ocean, and to minimise the impacts for PICTs in the west, revolve around: (i) 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 fish processing operations in the west, and (ii) optimising the productivity of tuna resources across the region.

Economic development and government revenue

The VDS is a good system for distributing the economic benefits of tuna for PNA member countries in the face of climatic variability (e.g. ENSO), and has the flexibility to allow the fishery to adapt to climate change. Allocation of vessel days to PNA members based on fishing effort history is adjusted regularly. If the projected eastward redistribution of tuna occurs under the changing climate, the periodic adjustment of allocated vessel days will reduce the need for members to trade fishing days. However, if a greater proportion of the stock and fishing effort occurs in high seas areas in the future, and the current limits to fishing are maintained, the benefits of the purse-seine VDS to PNA members will be reduced. For both locally-owned and flagged purse-seine and longline vessels, a key adaptation to the projected eastward distribution of tropical tuna species will be to secure rights to fish not only in EEZs but also in high seas areas.

To obtain sufficient skipjack and yellowfin tuna to supply their fish processing operations, PNG and Solomon Islands will need to: (i) maintain or secure arrangements for tuna caught in other EEZs to be landed in their ports; (ii) reduce the access of foreign fishing vessels to their EEZ to provide more fish for national vessels; (iii) require distant water fishing nations operating with their zone to land a proportion of catches for use by local canneries; and (iv) enhance existing arrangements for their national fleet to fish in other EEZs (Bell *et al*. 2011a), with PNG taking the lead in starting to implement many of these adaptations.

At the broader level of the regional management arrangements needed to optimise sustainable economic benefits from tuna for PICTs, the WCPFC struggles to negotiate and adopt adequate conservation and management measures that reduce fishing mortality to sustainable levels across all the relevant EEZs and high seas (Hanich and Tsamenyi 2014). Given current high levels of fishing, conservation measures are required that limit expanding fishing opportunities and inevitably distribute the burden of conservation measures to reduce catch in some or all participating States. Despite repeated proposals from FFA members, the WCPFC has failed to agree on sufficiently strong conservation measures that reduce mortality to sustainable levels without applying a disproportionate burden of conservation onto small island developing States. This is an ongoing threat to the long-term sustainability and economic development of the region's tuna fisheries and requires the development of new approaches, based on implementing decision-rules that transparently and equitably distribute the conservation burden in accordance with pre-agreed principles (Hanich and Ota 2013).

Other potential problems to adaptations by PICTs related to maintaining the economic benefits they receive from tuna are the existing investments in fishing vessels by distant water fishing nations fishing on the high seas (which are not covered by the VDS), and effort creep by such vessels (McIlgorm 2010). In addition, some fish processing facilities in vulnerable coastal areas may need to be climate-proofed or relocated as sea levels rise, and as more extreme inundation events occur, raising operating costs.

Food security

Increasing access to the rich tuna resources of the region (and expanding small pond aquaculture and developing fisheries for small pelagic fish) is a practical way of providing fish for local food security in the face of declines in coastal fisheries stocks due to climate change (see Fish, Shellfish and Coastal Fisheries paper, this volume). Indeed, the role of tuna in providing fish for PICTs that will face a gap in fish available for food in the future is profound – not only does the gap in available fish increase over time but tuna will have to supply an increasing percentage of the total fish required. Consequently, some countries will need to allocate more of the tuna resources within their waters to local food security or develop other ways to access the resource. Recent estimates indicate that across the region, ~6% of present-day tuna harvests from PICTs will be needed for this purpose by 2035. For PNG, the largest country in the region, ~10% of average tuna harvests from the nation's waters may be needed to help feed coastal and urban communities (Bell *et al*. 2015). Investments are now needed in cost-benefit analyses, in terms of outcomes for public health, comparing the benefits of maximising licencing revenues versus making a larger (but still relatively small) proportion of tuna available within the EEZ for local consumption.

Livelihoods

The projected eastward shift of tuna is expected to alter the availability of full-time jobs in offshore fisheries and associated onshore processing, and therefore reduce opportunities to earn income for many Pacific Islanders (Bell *et al*. 2011b). The adaptations required to minimise the loss of livelihoods derived from industrial tuna fisheries, and capitalise on the opportunities, include: securing supplies of fish for tuna fishing and processing operations within PICTs, tradable fishing rights between nations so industry can continue to target an eastward moving stock, and marketing environmentally-friendly products that provide a higher value per fish, compensating for the lower numbers of fish caught.

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