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Chapter 12: The Parties to the Nauru Agreement (PNA) 'Vessel Day Scheme': A cooperative fishery management mechanism assisting member countries to adapt to climate variability and change

Sangaalofa Clark,[1] Johann Bell,[2,3] Tim Adams,[4] Valérie Allain,[5] Transform Aqorau,[3,6] Quentin Hanich,[3] Vanessa Jaiteh,[7] Patrick Lehodey,[8] Graham Pilling,[5] Inna Senina,[8] Neville Smith,[5] Peter Williams,[5] Agnes Yeeting.[9]

[1]Parties to the Nauru Agreement Office, Majuro, Republic of Marshall Islands
[2]Conservation International, Arlington, the United States of America
[3]Australian National Centre for Ocean Resources and Security, University of Wollongong, Australia
[4]Pacific Islands Forum Fisheries Agency, Honiara, Solomon Islands
[5]Fisheries, Aquaculture and Marine Ecosystems Division, Pacific Community (SPC), Noumea, New Caledonia
[6] School of Government, Development & International Affairs, University of the South Pacific, Fiji
[7]Ministry of Natural Resources, Environment, and Tourism, Koror, Palau
[8]Collect Localisation Satellites, Ramonville, France
[9]Ministry of Fisheries and Marine Resources Development, Tarawa, Republic of Kiribati

Summary

The eight Pacific Island countries that are the Parties to the Nauru Agreement,[1] together with Tokelau, manage the largest tuna fishery in the world. As a group, these Small Island Developing States have developed a system to manage fishing effort, known as the Vessel Day Scheme (VDS). The system is an effective adaptation to the profound impacts of climate variability, i.e. the El Niño Southern Oscillation (ENSO), on the distribution and abundance of tuna within their combined exclusive economic zones (EEZs).

The VDS limits purse-seine fishing effort, defined in terms of fishing days, to an annual Total Allowable Effort (TAE). The TAE is allocated among the eight sovereign PNA members as a set of Party Allowable Effort limits (PAEs), based largely on recent effort history. Tokelau has a separate TAE/PAE that is adjusted in relation to changes to the PNA TAE. Parties can trade PAE days, and use a range of other VDS provisions, to adapt to the effects of ENSO. For example, during La Niña events, when most fleets prefer to fish in the west of the region, PNA members located there can buy days from those in the east. The converse occurs during El Niño episodes. The VDS ensures that the benefits of this fishery, which underpin the economies of many of the PNA members, can be distributed equitably, regardless of where the fish are caught within their EEZs.

The allocation of PAE is also a non-confrontational adaptation to climate change because it matches the climate-driven redistribution of tuna. However, adaptations to climate change-driven redistribution of tuna from the EEZs of PNA members into high-seas areas are also needed.

[1] Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands and Tuvalu.

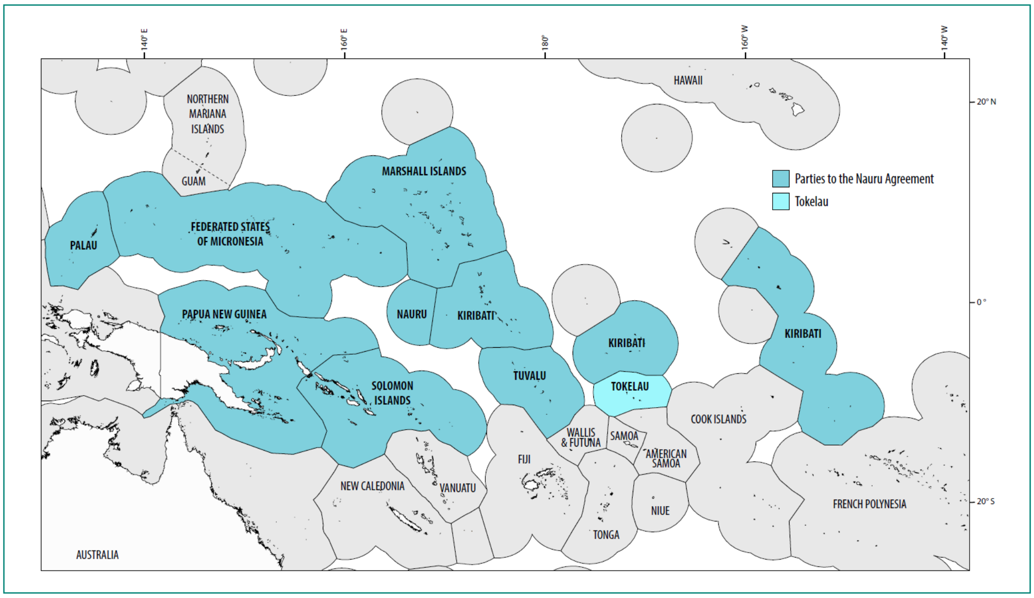

Figure 1. Map of the Pacific Islands region, showing the EEZs of the eight countries that are the Parties to the Nauru Agreement (PNA), and Tokelau.

A. Fishery context

This case study is based on the industrial purse-seine fishery targeting tropical tuna species in the combined EEZs of the eight Pacific Island countries that are the Parties to the Nauru Agreement (PNA) and Tokelau (Figure 1), an area of almost 13 million km[2]. For the purpose of this paper, reference to PNA includes Tokelau. In 2018, approximately 250 purse-seine vessels participated in this fishery, with ~35 percent of the vessels flagged in Pacific Island countries and ~65 percent from other member countries of the Western and Central Pacific Fisheries Commission (WCPFC) (Williams and Reid, 2019; Clark, 2019)

Between 2014 and 2018, the annual landed value of tuna caught by the PNA purse-seine fishery averaged USD 2.2 billion.3 However, because many of the PNA members do not have the opportunity to harness this value by participating in all parts of the supply chain, the economic benefits for these countries are derived mainly from fishing access revenue. This revenue makes extraordinary contributions to the economies of PNA members. In 2016, the total fishing access fees received by PNA members exceeded USD 450 million, providing between 28 percent and 98 percent of all government revenue for six4 of the nine PNA countries and approximately 5 to 10 percent for the other three5 members (FFA, 2018a, b). Across the region, the fishery also supports the employment of more than 20,000 people on fishing vessels, in fish-processing operations and fisheries management roles, including as onboard observers (FFA, 2018a).

The PNA purse-seine fishery targets skipjack tuna (which averaged 76 percent of the catch between 2014 and 2018), but also harvests smaller yellowfin and bigeye tuna (which comprised 20 percent and 4 percent of the average catch during that period, respectively). The total annual average catch from the PNA purse-seine fishery is 1.4 million tonnes (Table 1), and represents more than 50 percent of the recent (2014–2018) average tuna catch from the entire western and central Pacific Ocean (WCPO) of 2.7 million tonnes. This equates to almost 30 percent of the total global tuna supply (SPC, 2019a; Clark, 2019).

[2] Nauru Agreement Concerning Cooperation in the Management of Fisheries of Common Interest, https://www.pnatuna.com/content/nauru-agreement.

[3] WCPFC Area Catch Value Estimates, https://www.ffa.int/node/425.

[4] Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Tokelau and Tuvalu.

[5] Palau, Papua New Guinea and Solomon Islands.

Table 1. Total annual tuna catches (tonnes) between 2014 and 2018 from the EEZs of the Parties to the Nauru Agreement. FSM = Federated States of Micronesia, RMI = Republic of Marshall Islands, PNG = Papua New Guinea (Source: Pacific Community).

Year	FSM	Kiribati	RMI	Nauru	PNG	Palau	Solomon Is	Tuvalu	Tokelau	Total
2014	134 732	705 944	78 383	179 480	337 408	2 704	57 894	95 882	27 194	**1 619 621**
2015	160 645	613 357	31 657	67 107	189 007	185	100 174	76 783	44 134	**1 283 049**
2016	192 474	390 151	85 291	115 702	335 429	3 809	151 118	113 544	5 010	**1 392 527**
2017	191 165	377 258	27 880	82 295	377 397	12 698	158 726	53 328	33 546	**1 314 294**
2018	282 886	398 414	31 321	177 668	372 101	4 845	70 867	88 183	37 854	**1 464 138**
Average	**192 380**	**497 025**	**50 907**	**124 450**	**322 268**	**4 848**	**107 756**	**85 544**	**29 547**	**1 414 726**

The stocks of all three tropical tuna species caught by purse-seine in the WCPO are assessed to be in a healthy condition – none of the species are overfished, and none of them are currently subject to overfishing (Brouwer *et al.*, 2019). The healthy status of tuna stocks in the WCPO is due to the sound management arrangements implemented by PNA members (Section B), the Pacific Islands Forum Fisheries Agency (FFA) and WCPFC. The Oceanic Fisheries Programme at the Pacific Community (SPC) provides the science needed to assess the status of the tuna stocks, and the impacts of industrial tuna fishing on the ecosystem. The scientific advice provided by SPC that underpins the work of the tuna management agencies is evaluated annually by the WCPFC Scientific Committee.

Due to the comprehensive management arrangements implemented by PNA, FFA and WCPFC, levels of illegal, unreported and unregulated (IUU) fishing are low in PNA waters (MRAG, 2016).

B. Management context

PNA members manage purse-seine fishing in their EEZs through the 'Vessel Day Scheme'[6] (VDS) (Aqorau, 2009). The VDS was designed to enable PNA members to maximize their net economic returns from the sustainable use of tuna resources within their EEZs. To achieve this objective, the VDS applies a set of national, zone-based, transferable effort limits. This collaborative approach not only protects the sovereign rights of PNA members, but also enables them to implement sustainable conservation limits without bearing a disproportionate burden, and ensure that responsible fishing practices occur within their waters.

In legal terms, the VDS is a management scheme under the Palau Arrangement[7] (Aqorau, 2009), to which all PNA members are Parties. Tokelau has participated in the VDS since 2012 under the terms of a memorandum of understanding (MoU) with PNA. Under the VDS, purse-seine fishing effort, defined in terms of fishing days, is limited to an annual Total Allowable Effort (TAE). The TAE is an effort limit for purse-seine fishing in the EEZs of PNA members set within the broader range of measures for conservation and management of skipjack, yellowfin and bigeye tuna agreed by WCPFC.[8] These measures are agreed on a three- to four-year cycle, taking into account advice from the WCPFC Scientific Committee on the management of tropical tuna species targeted by the purse-seine fishery.

[6] Purse Seine Vessel Day Scheme, https://www.pnatuna.com/vds.

[7] Palau Arrangement for the Management of the Western Pacific Fishery as Amended, https://www.pnatuna.com/content/palau-arrangement-management-western-pacific-fishery.

[8] See Attachment 1, Table 1 of WCPFC Conservation and Management Measure, CMM 2018-01, https://www.wcpfc.int/doc/cmm-2018-01/conservation-and-management-measure-bigeye-yellowfin-and-skipjack-tuna-western-and.

The TAE is allocated among the eight PNA members as a set of Party Allowable Effort limits (PAEs), based largely on recent purse-seine effort history in each EEZ (Section D). In some years, estimates of tuna biomass in each EEZ have also been used in the formula for allocating PAE. Tokelau has its own separate TAE/PAE that is adjusted in relation to changes to the PNA TAE.

The Parties have substantial freedom in how they use their PAEs, but they are required to take all necessary measures, as adjusted by the provisions described in Section D(b), to ensure that their PAEs are not exceeded. Multilateral pooling arrangements are also used to provide access to the combined EEZs of several Parties, and one of these arrangements grants preferential access for vessels of the Parties to each other's EEZs.

Decisions on the VDS are generally taken by officials of Parties to the Palau Arrangement at meetings held at least annually. Where appropriate, issues arising from discussions by these officials are referred to meetings of Fisheries Ministers from PNA member countries. High-level oversight of the VDS is exercised by the Presidents/Prime Ministers of PNA member countries during occasional summits. The PNA office is required to brief the officials' meetings on catch and effort levels, any observed or potential effort creep, and any transfer of fishing days between Parties. Officials' meetings are also advised by the VDS Technical and Scientific Committee, and by the PNA Compliance Sub-Committee.

C. Climate implications

a) Effects of climate variability

The PNA VDS was designed from the start to take into account climate variability in the form of the variations in the distribution and abundance of skipjack tuna across the equatorial Pacific Ocean associated with ENSO events. The VDS design, described below, minimizes the effects of this interannual climatic variability on the equitable distribution of access revenue earned from the purse-seine fishery among PNA members (Geen, 2000; Aqorau *et al.*, 2018).

These effects stem from climate-driven variation in important features of the tropical Pacific Ocean, including upwelling of nutrient-rich water and sea surface temperature (Lehodey 2001; Ganachaud *et al.*, 2011), and the effects of this variation on the availability of micronekton (tuna prey) (Le Borgne *et al.*, 2011) and suitable spawning conditions for tuna (Lehodey *et al.*, 2011). In short, variation in ocean features influences the distribution of tuna, and the survival of eggs and larvae, with subsequent effects on purse-seine catches.

Despite the variable oceanic conditions, suitable habitat for tuna and areas for purse-seine fishing occur within the combined EEZs of PNA members every year. The prime area is the convergence zone between the two large ecological provinces dominating the equatorial Pacific Ocean: the 'western Pacific warm pool' and the 'Pacific equatorial divergence', also known as the 'cold tongue' (Le Borgne *et al.*, 2011). This convergence, which is several hundred kilometres wide, is characterized by relatively high concentrations of tuna prey and sea surface temperatures within the range preferred by skipjack tuna (Lehodey *et al.*, 1997, 2001, 2011).

The location of this convergence zone is influenced strongly by ENSO. During El Niño events, the warm pool can extend by up to 4 000 km, relocating the convergence zone further to the east (often within the EEZ of Kiribati). During La Niña episodes, the warm pool contracts and the convergence zone is located further west (often near the EEZ of PNG). Skipjack tuna follow the movement of the warm pool and convergence zone to remain in waters with relatively high concentrations of prey, and in conditions suitable for reproduction (Lehodey *et al.*, 1997). As a result, the locations where the best purse-seine catches are made correlate with the position of the warm pool and convergence zone (Lehodey *et al.*, 2011) (Figure 2).

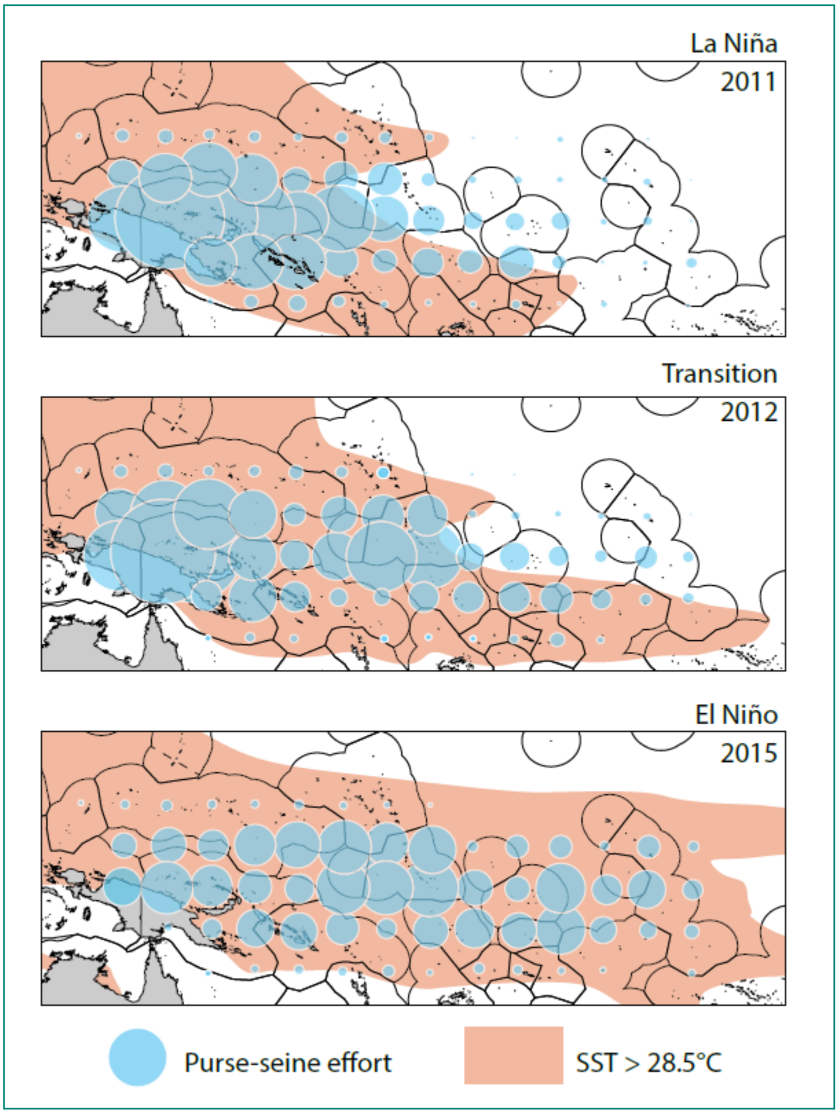

Figure 2. Examples of the influence of climatic variability (El Niño and La Niña events), and the associated extent of the western Pacific warm pool (defined by sea surface temperatures, SST, > 28.5 oC), on the distribution of purse-seine fishing effort in the tropical Pacific Ocean (source: Williams and Reid, 2018). The size of the blue circles indicates the level of fishing days in that 5ox5o square, with larger circles indicating relatively greater levels of fishing effort.

The east–west movements of skipjack tuna associated with the displacement of the warm pool have been demonstrated from tagging data (Lehodey *et al.*, 1997). Changes in the depth of the thermocline have also been proposed to explain the variability in purse-seine catch rates. During El Niño events, the thermocline becomes shallower in the west and deeper in the east. The opposite pattern occurs during La Niña periods. The depth of the thermocline influences the vertical distribution of skipjack, yellowfin and bigeye tuna; all of which generally remain above this strong vertical temperature gradient. A deeper thermocline allows fish to descend to greater depths, making them more difficult to catch with a purse-seine net deployed in surface waters, even where tuna are abundant. However, modern purse-seine fishing techniques (e.g. deeper nets) have reduced this difficulty, enabling fleets to take advantage of knowledge about the effects of climatic variability on the distribution and abundance of tuna.

b) Effects of climate change

The effects of continued high greenhouse gas (GHG) emissions on the distribution and abundance of tropical tuna species is modelled using a spatial ecosystem and populations dynamics model (SEAPODYM; Lehodey *et al.*, 2008; Senina *et al.*, 2008). Currently, bigeye tuna is primarily distributed in the eastern and central Pacific and its biomass in the western Pacific is limited, whereas skipjack and yellowfin tuna are primarily distributed in the western and central Pacific. The model indicates that the projected average distributions of skipjack and yellowfin tuna in 2050 generally approximate observed distributions of these species under strong El Niño conditions in recent decades (Figure 3) (Senina *et al.*, 2018). The biomass of skipjack and yellowfin tuna vulnerable to capture by purse-seine is projected on average to decrease in the EEZs of all PNA members except Kiribati by 2050 as the fish move progressively east, and to some extent poleward, into high-seas areas (Senina *et al.*, 2018; SPC, 2019b) (Table 2).

The redistribution of bigeye tuna is expected to be modest in the EEZs of PNA members, compared to skipjack and yellowfin tuna. Bigeye tuna has a longer life span and reaches larger sizes than skipjack and yellowfin tuna, and it has physiological adaptations to reach deeper ocean layers with low levels of dissolved oxygen concentration (Lowe *et al.*, 2000). These attributes provide bigeye tuna with a larger thermal habitat and the ability to dive regularly to the lower mesopelagic layer, increasing foraging opportunities. SEAPODYM simulates the differences in spawning and feeding habitat among tuna species and predicts a wider range of favourable spawning and feeding habitats for bigeye tuna (Table 2).

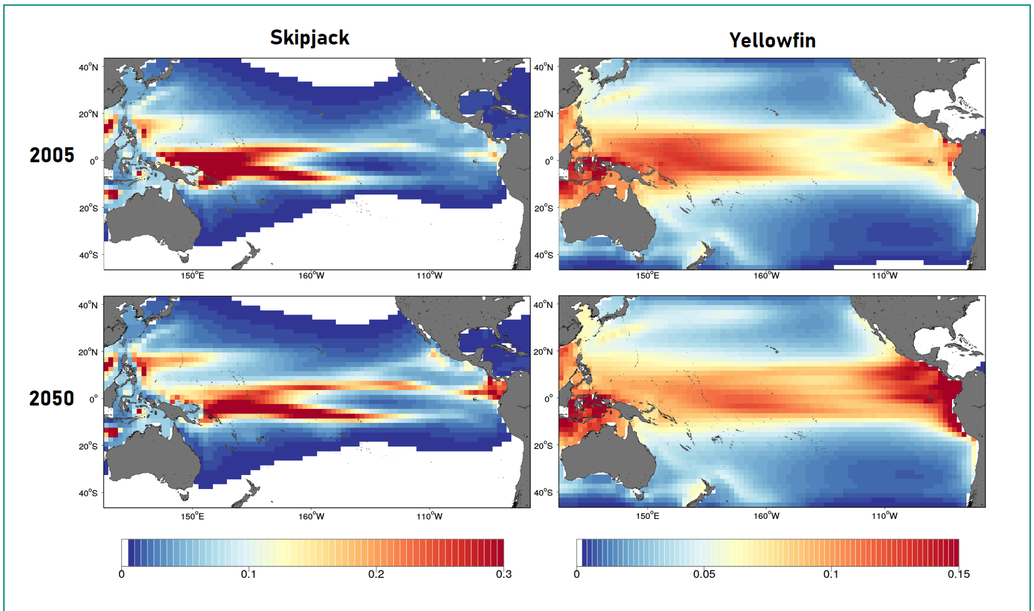

Figure 3. Projected mean distributions of skipjack and yellowfin tuna biomass across the tropical Pacific Ocean under a high-emissions scenario (IPCC RCP8.5) in 2050, relative to 2005 (Senina *et al.*, 2018).

Table 2. Projected changes (%) in biomass of skipjack, yellowfin and bigeye tuna by 2050 under a high-emissions scenario (IPCC RCP8.5) in the EEZs of the Parties to the Nauru Agreement (PNA) (source: Senina et al., 2018).

PNA EEZ		Skipjack	Yellowfin	Bigeye
West of 170°E	FSM	-29	-19	+3
	Marshall Islands	-17	-12	-3
	Nauru	-8	-16	-4
	Palau	-28	-12	+4
	Papua New Guinea	-43	-21	-4
	Solomon Islands	-17	-9	-2
East of 170°E	Kiribati	+18	+7	+1
	Tuvalu	-12	+3	-2
	Tokelau	-14	+14	-1

Based on this modelling, the average annual purse-seine catch from the combined EEZs of PNA members is projected to decrease by 10 percent (~140 000 tonnes) by 2050. Preliminary economic assessments indicate that total access revenue collected by PNA members could decrease by more than USD 60 million per year in the decades ahead (Table 3) (SPC, 2019b). Significant loss of tuna biomass can also be expected to reduce other opportunities to derive wealth from tuna, and to disrupt the Regional Roadmap for Sustainable Pacific Fisheries (FFA and SPC, 2015).

Table 3. Tuna access fees earned by PNA members in 2016, and projected changes in access fees and total government revenues by 2050 due to redistribution of tuna. Projected changes in tuna biomass are averages for skipjack (SKJ), yellowfin (YFT) and bigeye (BET) tuna (Table 2), weighted by 76%, 20% and 4%, respectively (adapted from SPC, 2019b).

PNA member	Tuna access revenue 2016 (USD million)	Change (%) in combined biomass of SKJ, YFT & BET tuna by 2050	Tuna access revenue 2050 (USD million)	Change from 2016 to 2050	
				Tuna access revenue (USD million)	Loss/gain in total gov't revenue (%)
West of 170°E					
PNG	128.8	-37	81.1	-47.7	-1.8
FSM	63.2	-26	46.8	-16.4	-14.6
Palau	6.8	-24	5.2	-1.6	-2.1
Marshall Islands	29.2	-15	24.8	-4.4	-9.0
Solomon Islands	41.6	-15	35.4	-6.2	-1.5
Nauru	27.8	-9	25.3	-2.5	-2.5
East of 170°E					
Tuvalu	23.4	-9	21.3	-2.1	-5.6
Tokelau	13.3	-8	12.2	-1.1	-7.8
Kiribati	118.3	+15	136.0	+17.7	+9.9

Another important result of the progressive redistribution of tuna from the combined EEZs of PNA members to high-seas areas is that a lower proportion of tuna biomass supporting the purse-seine fishery will be under the jurisdiction of PNA member countries.

D. Adaptations and lessons

a) Stock assessment and management advice

Knowledge of the effects of ENSO on the distribution and abundance of tuna has been incorporated to some extent into the integrated models used to assess the status of tuna stocks in the WCPO, particularly to refine estimated recruitment levels. However, stock assessment models either require assumptions about key biological parameters (e.g. growth, natural mortality), or estimate those parameters from supplied historical data. These biological parameters are currently assumed to be constant through space and time and so do not capture or easily incorporate the long-term effects of historical climate change.

There is also more scope for including the effects of ENSO, rather than the implications of climate change, in the development of harvest strategies for tuna stocks currently underway by the WCPFC (WCPFC, 2014, 2015). Development of these harvest strategies involves the design, testing and implementation of management procedures, which invoke pre-agreed decisions on data collection, assessment and management action, defined through harvest control rules. These rules need to be robust to uncertainties, and define future fishing opportunities to achieve specified management objectives and maintain stocks around corresponding target reference points.

Inclusion of the effects of climate change in future stock assessment models and harvest strategies will eventually need to incorporate information on the stock structure of tuna. Recent research on the population genetics of tuna species (Grewe *et al.*, 2015; Anderson *et al.*, 2019a,b) indicates that spatial structuring does occur within some of the tropical tuna species (Moore *et al.,* 2020a), and highlights the need to determine the number of self-replenishing stocks for each tuna species and their respective spawning grounds (Moore *et al.,* 2020b; see also Rodriguez-Espeleta *et al.*, 2019). The explicit description of fish movements, including feeding and spawning migrations, and the use of a robust parameter estimation method within SEAPODYM (Senina *et al.*, 2008, 2020), are also expected to help predict the occurrence of self-replenishing stocks for each tuna species.

Investments are now needed to: 1) identify the spatial structure of tropical Pacific tuna stocks; i.e. the number of self-replenishing populations ('stocks') within the geographical range of each tuna species; 2) gather new and independent data to strengthen model predictions for the responses of each stock under both high- and low-GHG emissions scenarios; and 3) compile integrated assessments of the effects of climate change on the expected redistribution of each tropical Pacific tuna species within its geographical range for each GHG emissions scenario (SPC, 2019b).

b) Formulation of norms to regulate harvest and access to resources according to established objectives

<u>The PNA VDS and the WCPO tuna fishery</u>

The WCPO tuna fishery is managed through conservation and management measures (CMM) agreed to and adopted by the WCPFC (Commission). The current CMM for tropical tuna (TT CMM) includes purse-seine effort limits for the high seas and EEZs over three-year periods, in addition to limits for other fisheries, especially longline (LL) fisheries. The TT CMM is evaluated each year for potential performance against management objectives.

Within the CMM, the PNA purse-seine effort limit is implemented through the VDS TAE, which covers approximately 80 percent of the WCPO purse-seine tuna fishery. For PNA, the VDS days are monitored using an electronic vessel tracking system and the TAE and PAEs are reviewed annually.

In theory, the PNA VDS could be expanded to cover the whole WCPO purse-seine fishery. In the past, some other Pacific Island countries have expressed an interest in participating in the PNA VDS – Tokelau was the first to do this, and was successful. However, the practical difficulties associated with maintaining the VDS coalition have resulted in it continuing to be limited to the 'like-minded' group of PNA members and Tokelau.

Like PNA, WCPFC annually assesses whether commission members: (i) have properly implemented the measures through their national laws; and (ii) are enforcing the laws effectively for their vessels and/or in their waters. To do this, WCPFC uses information from a range of reporting and monitoring arrangements, including onboard observers, vessel tracking, and inspections at sea and in port.

As mentioned in Section A, the WCPFC Scientific Committee regularly assesses the stock status of each tuna species. This is done comprehensively for each of the four main species at least once every three years. Reviews of short-term stock status indicators are also made annually for each of the four species. The WCPFC uses this information, and evaluations of the effectiveness of the management measures, to make annual adjustments where appropriate.

As noted, the Commission is also moving towards longer-term harvest strategies that will include agreed target reference points (TRPs) that reflect overall fishery management objectives, and mechanisms for adjusting catch and effort when the status of a tuna fishery is not consistent with the TRPs.

Interannual climate variability

Several elements of the structure of the VDS enable the performance of this fishing effort scheme to adapt to climatic variability. They include transferability, pooling, roaming and PAE adjustments. PAE vessel days can be transferred freely between Parties, and consequently between EEZs, but not between vessel operators. Inter-Party transferability, as a response to the effects of ENSO on skipjack tuna, was proposed during the design of the VDS, with the original proposal advising that *'Given the scale of fluctuations in abundance in some EEZs, transferability of fishing days between Parties will be an essential component of the management system'* (Geen, 2000).

In general, the transferability provision of the VDS can be seen as a trading mechanism among PNA members, allowing them to respond to the effects of ENSO on the prime fishing grounds for skipjack tuna (Aqorau *et al.*, 2018). During La Niña events, when the fleets fish in the west of the region, the countries there can buy days from members in the east. The converse occurs during El Niño episodes. Thus, regardless of where the fish are caught, all PNA members can receive license revenue each year.

When Parties pool fishing days, vessels purchasing pooled days can use them in the EEZs of any of the Parties contributing to the pool, increasing the value of the days and the scope for effort to be adjusted in response to changes in distribution of tuna, and variation in fishing conditions more generally. There are two major

[9] There is a separate allocation of days solely for the Kiribati EEZ, which is the most important EEZ for fishing by the United States of America fleet.

pooling arrangements – one for the United States of America fleet, which includes eight of the nine Parties and excludes Kiribati,[9] and one between five of the Parties (Marshall Islands, Nauru, Solomon Islands, Tuvalu and Tokelau).

Roaming enables fishing days to be used outside the EEZ of the PAE holder without the processes of transfer or pooling. The roaming arrangements enable domestic vessels of PNA members to fish in other Parties' EEZs beyond their home Party's EEZ, using fishing days provided from the PAE of their home Party. Designed primarily to provide support for the development of domestic fleets, roaming allows for greater flexibility in adjusting effort to short-, medium- and long-term changes in distribution of tuna resources targeted by purse-seine fishing. In 2018, domestic fleets accounted for 35 percent of the fishing effort under the VDS, and roaming is expected to increase this percentage further.

In addition, there have been varying forms of allocation models used to adjust PAEs, which have made the VDS responsive to climatic variability. The current allocation model no longer uses estimated tuna biomass within an EEZ as a factor in the allocation because of difficulties in making these estimates at the national scale, and because of the high degree of intra-regional variability from year to year. Rather, the allocation of PAE is based substantially on recent (previous eight to ten years) fishing effort within the Party's EEZ. Under this arrangement, the PAE allocations reflect the patterns of fishing effort driven by the influence of ENSO on the distribution of tuna, and enabled by the transferability, pooling and roaming provisions of the VDS.

Some examples of the implications of climatic variability for PNA members, and the ways they benefit from the provisions of the VDS, are summarized below.

<u>Kiribati:</u> With the largest EEZ area of all PNA members, Kiribati is at the eastern end of the range of the western and central Pacific tropical purse-seine fishery and hosts much of the effort by this fishery during El Niño events. Another feature is that Kiribati has closed 40 percent of its Phoenix Islands EEZ (one of the nation's three non-contiguous EEZs, the others being the Gilbert Islands and Line Islands EEZs) to commercial fishing. As the warm pool expands and the centre of distribution of the skipjack tuna stock moves east towards Kiribati over the next few decades (Figure 3), the VDS will enable Kiribati – if it wishes – to non-confrontationally obtain the rights to increase EEZ effort limits by acquiring days from other PNA EEZs further west, and thereby gradually increase its PAE (i.e. its share of the total purse-seine fishery). Without the PNA and the VDS, the consequences of this kind of climate-driven shift in skipjack tuna biomass would have to be accommodated by continuous and uncertain political negotiations within WCPFC. Like other tuna regional fisheries management organizations, WCPFC still lacks an adaptive and equitable fishing rights allocation framework, particularly one that can respond to climate change-induced shifts in fish biomass.

<u>Nauru:</u> Although Nauru has the smallest EEZ of any of the eight PNA members, its EEZ attracts considerable purse-seine effort because the convergence zone often occurs in the vicinity of the country during both El Niño and La Niña events. Even during strong El Niño events, there can be demand for days because purse-seine vessels often move between the east and central Pacific without going to the west. As a result, the average tuna catch from Nauru's EEZ is the fourth highest among all PNA members (Table 1). It is also interesting to note that the average purse-seine 'catch density' of tuna in Nauru's EEZ (78 kg per km^2 per year) is higher than for

any other PNA member, and at least twice as high as for Kiribati and PNG. The pooling and roaming provisions of the VDS should assist Nauru to maintain PAE as the average position of the convergence zone moves eastward due to ocean warming.

Palau: Relatively low purse-seine fishing effort has occurred in Palau's EEZ since implementation of the VDS. Even lower levels of purse-seine effort are expected to occur in the future because the Palau National Marine Sanctuary (PNMS) Act, signed into law in 2015, resulted in the closure of 80 percent of the EEZ to all fishing, effective 1 January 2020. A practical approach to using the provisions of the VDS for Palau in the years ahead is likely to involve: (i) preserving transferability so that days can continue to be traded in response to demand created by El Niño events, even though there is a net redistribution of tuna to the east; and (ii) joining the five pooling Parties to maintain PAE, enhance the value of allocated days, and optimize revenue following the implementation of the PNMS.

Climate change

The methods for allocating PAE, and the pooling and roaming provisions of the VDS, are expected to also provide non-confrontational adaptations to climate change. Eastward redistribution of tuna (Figure 3) could result in proportional changes in allocation of PAE among PNA members. The latest modelling (Senina *et al.*, 2018) indicates that during the next couple of decades, Parties in the central and eastern regions of the WCPO could accumulate PAE, whereas Parties in the west may gradually lose PAE. However, by 2050, the PAE of all PNA members, except Kiribati, could be reduced to some extent by climate-driven redistribution of tuna. The VDS may buffer these potential impacts. The formula for allocating PAE (based on the past eight to ten years of effort history) will provide Parties with time to adapt. The pooling and roaming provisions can also be expected to provide some opportunities to help Parties maintain PAE, through use of their days further to the east.

However, as explained in Section D(a), there is still significant uncertainty associated with the current modelling with SEAPODYM stemming from multiple sources, such as biases in coarse spatial and temporal resolutions; coupled, global circulation and biogeochemical model predictions (Matear *et al.*, 2015); stock structure; imperfections in fishing data used in model fitting; and the structural uncertainty of the model itself, including the forage sub-model for which limited validation is possible due to the weak availability of forage observations. A robust, integrated modelling approach is needed, including estimation of forecast uncertainties and identification of the spatial structure of tuna stocks, before the potential risks to longer-term changes in PAE can be identified with confidence.

A separate, key issue for PNA members is to identify how to retain the full present-day benefits that they receive from their shared tuna resources, in a non-confrontational way, as tuna resources caught by purse-seine fishing move progressively into high-seas areas (Pinsky *et al.*, 2018; SPC, 2019b). In particular, PNA members are looking to secure a greater share of the benefits from high-seas fishing to compensate for the reduction in EEZ fishing opportunities and the adverse effects of climate change more generally.

c) Monitoring, control and surveillance

Monitoring the responses of tropical tuna species to climate change is essential but expensive. Monitoring changes in distribution and abundance of tuna among the EEZs of PNA members will continue to be done through: (i) the routine obligations for vessels to report catch, effort and other details to national and regional agencies; and (ii) verification of this information by independent observers onboard all purse-seine vessels. This monitoring also covers vessels fishing in the high seas because vessels are required to report on their fishing in the high seas as a condition of licences to fish in EEZs and under WCPFC requirements. This should ensure that effective monitoring of the purse-seine fleet is maintained, even if there is some shift in biomass of tuna to high-seas areas. Nevertheless, it will be important to continue to strengthen monitoring, including through the use of electronic and video systems, to ensure that this outcome is achieved.

In addition, while ongoing tuna tagging programmes and fishery observers collecting biological samples will help monitor changes in the tuna stocks, further support is needed to monitor and improve knowledge of the physical, chemical and biological features of the tropical Pacific Ocean that affect the abundance and distribution of tuna stocks. This information will increase the effectiveness of the global climate models and biogeochemical models used to inform SEAPODYM (Lehodey *et al.*, 2011), and will improve and validate the forage sub-model developed within SEAPODYM.

Purse-seine vessels fishing in PNA waters can make a significant contribution to the monitoring of fish abundance and ocean variables. For example, PNA members currently receive tracking data from satellite buoys attached to drifting fish aggregating devices (dFADs), and almost all of these buoys transmit fish biomass data (Escalle *et al.*, 2019a). Some preliminary work has been undertaken on using this data for scientific purposes (Escalle *et al.*, 2019b). A proposed new PNA FAD registration and tracking management measure provides scope for this information to be gathered systematically in the future.

Recommendations

The PNA members have demonstrated that fisheries targeting transboundary stocks affected by climatic variability can be managed cooperatively to distribute the benefits equitably. These Pacific Small Island Developing States have also shown that, providing target fish resources remain largely within their combined EEZs, the agreed allocations of fishing effort based on recent historical effort in each EEZ provides a non-confrontational way of adjusting the distribution of benefits as fish migrate in response to climate change.

Problems may arise, however, when climate-driven redistribution of fish results in a proportion of the resources moving from the combined EEZs of collaborating countries to high-seas areas and EEZs of countries that are not VDS participants. The effective management of the PNA purse-seine fishery, which has helped ensure that tuna resources have not been overfished or subjected to overfishing, raises a significant question about appropriate stewardship arrangements under future climate change scenarios. A pertinent question is whether countries that have demonstrated that they can manage transboundary fish stocks effectively should be given the opportunity to continue to do so when a proportion of the resource moves to high-seas areas. This question is particularly relevant to Pacific Small Island

Developing States, given the extraordinary dependence of their economies on tuna (Section A) (FFA, 2018a,b; SPC, 2019b), and their negligible contribution to the GHG emissions responsible for ocean warming and the redistribution of tropical Pacific tuna species. Fortunately, the WCPFC Convention requires consideration of such issues when determining allocations and/or fishing rights. For example, Article 10 requires the Commission, when considering criteria for allocation, to take into account, inter alia, the respective contributions of participants to conservation and management, and their record of compliance with conservation and management measures (WCPFC Convention, 2000).

Reducing uncertainty in the expected redistribution of fisheries resources due to climate change will assist in resolving this dilemma. Reducing uncertainty will depend on identifying the spatial structure of fish stocks, where such information does not exist already. Reliable maps of projected climate-driven changes in distribution and abundance of a fisheries resource among EEZs, and between EEZs and high-seas areas, cannot be produced unless the number, size and location of each stock are identified, and the response of each stock to climate change is correctly addressed by the modelling.

The models used to assess the likely responses of stocks to climate change (e.g. SEAPODYM) can also be progressively improved. Fishing fleets licensed to fish in the EEZs of countries managing transboundary stocks and on the high seas can play an important role in this. Licence conditions and/or incentives can be developed to ensure that fishing fleets contribute to the collection of physical and biological data at the scale needed to improve the predictive skills of global climate models, biogeochemical models, and forage and fish spatial dynamics models.

The experience gained by PNA in operating the VDS should provide useful insights for management of other transboundary stocks where the distribution of a target species varies over time due to climate variability, or where climate change is causing a shift in the range of the species across national boundaries. Indeed, the Environmental Defense Fund (EDF, 2018) has already identified that some of the key elements of the VDS would be useful for addressing difficulties that have arisen due to climate change in the governance of shared stocks in the North East Atlantic.

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