



OPEN ACCESS

EDITED BY

David Lee VanderZwaag,
Dalhousie University, Canada

REVIEWED BY

Brian Pentz,
University of Toronto Scarborough,
Canada
Aryuni Yuliantiningsih,
Universitas Jenderal Soedirman,
Indonesia
Shuya Nakatsuka,
Japan Fisheries Research and
Education Agency (FRA), Japan

*CORRESPONDENCE

Camille Goodman
cgoodman@uow.edu.au

SPECIALTY SECTION

This article was submitted to
Ocean Solutions,
a section of the journal
Frontiers in Marine Science

RECEIVED 16 September 2022

ACCEPTED 09 November 2022

PUBLISHED 14 December 2022

CITATION

Goodman C, Davis R, Azmi K, Bell J,
Galland GR, Gilman E, Haas B,
Hanich Q, Lehodey P,
Manarangi-Trott L, Nicol S,
Obregon P, Pilling G, Senina I, Seto K
and Tsamenyi M (2022) Enhancing
cooperative responses by regional
fisheries management organisations to
climate-driven redistribution of
tropical Pacific tuna stocks.
Front. Mar. Sci. 9:1046018.
doi: 10.3389/fmars.2022.1046018

COPYRIGHT

© 2022 Goodman, Davis, Azmi, Bell,
Galland, Gilman, Haas, Hanich, Lehodey,
Manarangi-Trott, Nicol, Obregon, Pilling,
Senina, Seto and Tsamenyi. This is an
open-access article distributed under
the terms of the [Creative Commons
Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use,
distribution or reproduction in other
forums is permitted, provided the
original author(s) and the copyright
owner(s) are credited and that the
original publication in this journal is
cited, in accordance with accepted
academic practice. No use,
distribution or reproduction is
permitted which does not comply with
these terms.

Enhancing cooperative responses by regional fisheries management organisations to climate-driven redistribution of tropical Pacific tuna stocks

Camille Goodman^{1*}, Ruth Davis¹, Kamal Azmi¹,
Johann Bell^{1,2}, Grantly R. Galland³, Eric Gilman⁴, Bianca Haas¹,
Quentin Hanich¹, Patrick Lehodey⁵, Lara Manarangi-Trott⁶,
Simon Nicol^{5,7}, Pablo Obregon², Graham Pilling⁵,
Inna Senina⁵, Katherine Seto⁸ and Martin Tsamenyi^{1,9}

¹Australian National Centre for Ocean Resources and Security (ANCORS), University of Wollongong, Wollongong, NSW, Australia, ²Center for Oceans, Conservation International, Arlington, VA, United States, ³The Pew Charitable Trusts, Washington, DC, United States, ⁴Pelagic Ecosystems Research Group, The Safina Center, Honolulu, HI, United States, ⁵Oceanic Fisheries Programme, Pacific Community (SPC), Noumea, New Caledonia, ⁶Western and Central Pacific Fisheries Commission (WCPFC), Pohnpei, Micronesia, ⁷Centre for Conservation Ecology and Genomics, Institute for Applied Ecology, University of Canberra, Canberra, ACT, Australia, ⁸Environmental Studies Department, University of California at Santa Cruz, Santa Cruz, CA, United States, ⁹African Centre of Excellence in Coastal Resilience (ACEcor), University of Cape Coast, Cape Coast, Ghana

Climate change is predicted to alter the distributions of tropical tuna stocks in the Pacific Ocean. Recent modelling projects significant future shifts in tuna biomass from west to east, and from national jurisdictions to high seas areas. As the distributions of these stocks change, the relevant regional fisheries management organisations (RFMOs)—the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC)—will need to develop an expanded framework for cooperation and collaboration to fulfil their conservation and management responsibilities under international law. The key elements of a possible expanded framework for cooperation can be developed, and fundamental areas for collaboration identified, by applying and adapting principles established in the United Nations Convention on the Law of the Sea, the United Nations Fish Stocks Agreement, and the constituent instruments of the RFMOs themselves. Our analysis reveals a wide range of important issues requiring cooperation, and three clear priorities. First, a formal mechanism for cooperation is needed to enable effective and efficient decision-making and action by the two RFMOs on key issues. Second, further cooperation is required in scientific research and modelling to better understand the biology and distributions of Pacific tuna stocks and how they will respond to climate change, and to inform stock assessments and harvest strategies. Third, the RFMOs must cooperate to define appropriate limits on fishing for each stock in

a way that ensures they are compatible across the two organisations, taking into account their different members and management regimes.

KEYWORDS

fisheries, climate change, stock distribution, RFMOs, cooperation, WCPFC, IATTC, UNCLOS

Introduction

Climate change will disrupt and alter international fisheries management worldwide. Changes in the distribution, abundance and growth of fish stocks will alter fishing pressures and fishing practices, challenge the acceptance and effectiveness of international management regimes, and produce a wide range of social, economic and security impacts (see, e.g., Mendenhall et al., 2020; Østhagen et al., 2020; Barhri et al., 2021). Whether measured by reference to the viability of national fishing fleets, the food and economic security of small island developing States (SIDS), the potential for an increase in illegal fishing and fisheries-driven conflicts as industrial fleets ‘follow the fish’, or the possibility of a governance failure or breakdown in cooperation between the members of a regional fisheries management organisation (RFMO), the stakes are high and

the risks are real (see e.g., Pinsky et al., 2018; Bell et al., 2021; Spijkers et al., 2021). All of these risks are present in the Pacific Ocean, where climate change will alter the distributions of tropical tuna stocks in the world’s largest tuna fishery.

Recent modelling shows that continued greenhouse gas emissions are expected to cause substantial changes in the distributions of skipjack, yellowfin and bigeye tunas within the Pacific Ocean Basin, with predicted shifts in biomass from the Western and Central Pacific Ocean (WCPO) toward the Eastern Pacific Ocean (EPO), and from areas under national jurisdiction to the high seas (Bell et al., 2021) (Figure 1). The scale of this projected redistribution is substantial. By 2050, under the Intergovernmental Panel on Climate Change representative concentration pathway (RCP) 8.5 emissions scenario, the total biomass of these three tuna species is projected to decrease by an average of 13% in the combined

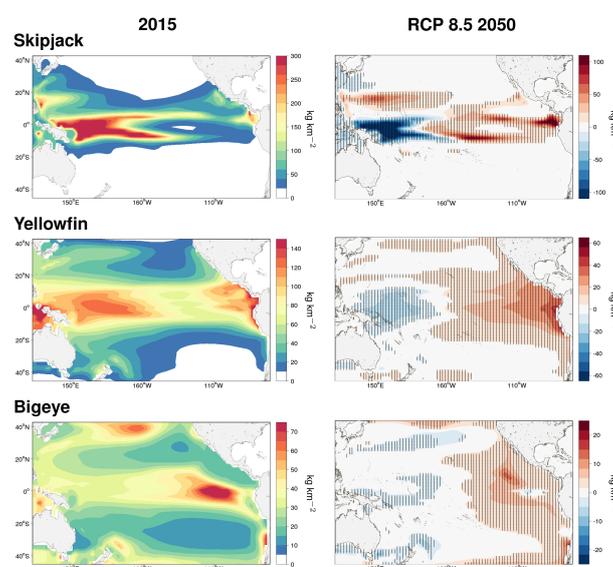


FIGURE 1
Average biomass distributions (kg km^{-2}) of skipjack, yellowfin and bigeye tuna in the Pacific Ocean basin for 2015 (2011–2020) (left), and mean anomalies (kg km^{-2}) from the average 2015 biomass distribution of each tuna species projected to occur by 2050 (2044–2053) under the RCP 8.5 greenhouse gas emissions scenario (right). Shading indicates areas where projections from four Earth System Models agree in the sign of change. Source: Bell et al. (2021).

exclusive economic zones (EEZs) of the 10 Pacific small island developing States and territories (Pacific SIDS) in the WCPO, where most purse-seine fishing for tuna in the Pacific currently occurs, and increase in high seas areas (Bell et al., 2021). The redistribution of tuna to the central area of the Eastern Pacific Ocean (EPO-C) is particularly pronounced (Table 1): under the RCP 8.5 emissions scenario, the total biomass of the three species caught by purse seine in the EPO-C high seas area by 2050 is expected to increase by an average of 23% (673,000 tonnes), relative to the period 2011–2020. Even under the lower RCP 4.5 emissions scenario, the total biomass is projected to increase in the EPO-C by 18% (528,000 tonnes) (Table 1).

The climate-driven redistribution of Pacific Ocean tuna stocks creates major challenges, not only for the Pacific SIDS that depend on tuna fishing access fees for government revenue (Bell et al., 2021), but also for the RFMOs that manage them: the Western and Central Pacific Fisheries Commission (WCPFC) in the WCPO, and the Inter-American Tropical Tuna Commission (IATTC) in the EPO. At present, these RFMOs cooperate on a limited range of issues through collaborative arrangements that are based on a small area of geographical overlap between their Convention Areas, shared fish stocks, and vessels that may potentially fish in both Convention Areas. However, based on current predictions, it is clear that climate-driven changes in the distributions and biomass of key tuna stocks will produce

complex challenges that require a more comprehensive response. In particular, as the geographical distributions of tropical tuna stocks change, closer cooperation and coordination will be required to ensure that the combined catch taken across both Convention Areas is managed to ensure stocks are conserved effectively both within and beyond EEZs, as required by international law. Although many of the decisions that will be needed to ensure this outcome cannot be taken until the actual effects of these climate-driven changes become clearer, there are a range of actions that members of WCPFC and IATTC must take now (consistent with the precautionary approach required by international law) to develop a framework that will support timely, equitable and effective decision making by both organisations in response to these challenges.

Here, we seek to understand how the legal and practical challenges arising from the climate-driven redistributions of tropical tuna stocks will affect cooperation and collaboration between these two RFMOs. In Section 2, we examine how the international legal framework for fisheries management provides for this situation, and specifically, how (or whether) it addresses cooperation and collaboration between RFMOs. In Section 3, we focus on how these issues are addressed at the regional level, looking at the legal frameworks governing the operation of WCPFC and IATTC, and existing forms of cooperation

TABLE 1 Projected changes in total biomass of the three tropical tuna species caught by purse seine (skipjack, yellowfin and bigeye tuna) in high seas areas of the Western and Central Pacific Ocean (WCPO) and Eastern Pacific Ocean (EPO) under RCP 8.5 and RCP 4.5 greenhouse gas emission scenarios by 2050, relative to reference biomass for the period 2011–2020.

High-seas areas	Reference biomass 2011–2020 (tonnes)	RCP 8.5 in 2050		RCP 4.5 in 2050	
		Change in biomass (%)	Change in biomass (tonnes)	Change in biomass (%)	Change in biomass (tonnes)
WCPO					
I1	142,448	-22.3	-31,834	-9.7	-13,874
I2	390,718	-26.2	-102,317	-9.6	-37,491
I3	523,315	+16.7	+87,440	+18.9	+98,857
I4	640,495	-0.5	-3,194	+4.8	+30,451
I5	819,849	+14.7	+120,747	+13.1	+107,541
I6	1,096,355	+3.2	+35,028	+5.2	+56,917
I7	589,614	+3.4	+20,210	+3.4	+20,303
I8	14,418	+5.9	+855	+10.3	+1,489
I9	12,605	+17.5	+2,204	+10.3	+1,299
H4	76,040	-12.7	-9,636	+8.9	+6,787
H5	220,544	+4.2	+9,182	+3.9	+8,607
EPO					
EPO-N	746,544	+15.2	+113,486	+13.6	+101,608
EPO-C	2,884,220	+23.3	+673,129	+18.3	+527,853
EPO-S	327,118	+22.1	+72,210	+12.5	+40,727
Total	8,484,283	+11.6	+987,510	+11.2	+951,075

See Figure 2 for locations of high seas areas. Source: Projections are averages from modelling informed by four different Earth System Models, see the source publication (Bell et al., 2021) for details.

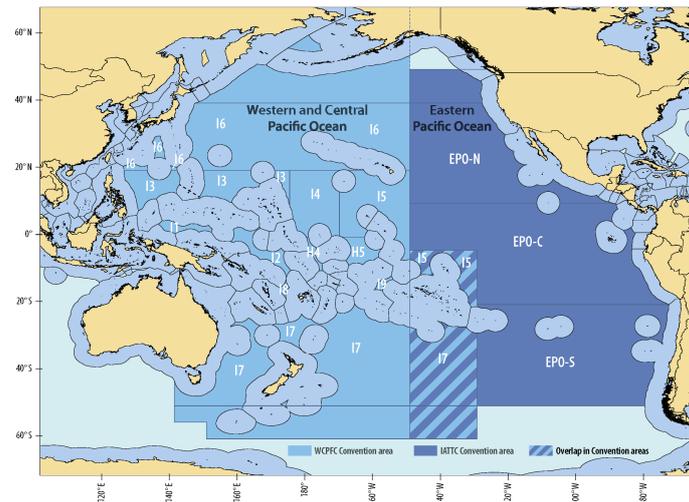


FIGURE 2

Map of the Pacific Ocean basin showing the Convention Areas of the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC) and the locations of the high seas areas referred to in Table 1. Source: Bell et al. (2021).

between the two organisations. In Section 4, we examine four key areas of RFMO activity—governance structures, science and research, conservation and management, and compliance and enforcement—to identify practical issues that will require further cooperation and collaboration to facilitate the effective management of tropical Pacific tuna stocks as they are redistributed due to climate change. Section 5 highlights actionable recommendations for consideration by these RFMOs and identifies issues requiring further analysis.

This study approaches climate change, fisheries and cooperation from a new perspective, by seeking to understand how RFMOs can and should interact with each other to respond effectively to emerging realities in the context of climate change. A number of studies have provided useful insights into how climate change impacts will challenge cooperation *within* individual RFMOs—focusing on the institutional weaknesses common to most RFMOs, the need to integrate climate change impacts into decision-making, and the difficulty of reaching a consensus on equitable approaches to allocation (Mendenhall et al., 2020; Pinsky et al., 2018; Rayfuse, 2019). This study builds on this body of literature and turns this consideration outwards, focusing on the challenges of cooperation *between* RFMOs that will arise as climate change leads to overlaps and interactions between the mandates and jurisdiction of adjacent RFMOs. Although this study is undertaken in a specific regional context—considering the geography, oceanography, biology, membership, and institutional frameworks of RFMOs in the Pacific Ocean—it provides a starting point for examining the interactions and cooperation that might be needed between RFMOs in other regions.

The global framework: UNCLOS and UNFSA

The existing framework for international fisheries law provides very limited direction regarding cooperation between RFMOs on measures to manage climate-driven changes to the abundance and distribution of fish stocks. In many respects, this reflects the inherent nature (and limits) of international law, in which States (and not international organisations) are the primary actors. The global framework for international fisheries is focused primarily on the rights and obligations of individual States, and the duty to cooperate is envisaged to apply to coastal and flag States and within the framework of an individual RFMO, and not to or between RFMOs. Nevertheless, a number of principles in the global framework can be drawn on to support an argument for enhancing cooperation between RFMOs.

UNCLOS

The global framework for international fisheries management is underpinned by the 1982 *United Nations Convention on the Law of the Sea* (UNCLOS) and, in particular, by the ubiquitous ‘duty to cooperate’. UNCLOS assigns responsibility for fisheries management based upon a regime of maritime zones, with coastal States accorded primary responsibility for stocks within their EEZs, and responsibility for fishing on the high seas placed primarily on the flag States of fishing vessels. However, for ‘straddling’ stocks (whose range

straddles the EEZ of two or more countries, or straddles areas of both EEZ and high seas) and ‘highly migratory’ stocks (whose migratory range may extend across areas of EEZs and high seas), responsibility must be coordinated between relevant coastal and flag States, and the duty to cooperate is key.

In relation to highly migratory species (including the major commercial tuna species), flag States and coastal States whose waters fall within the range of a highly migratory species must cooperate with a view to ‘ensuring conservation and promoting the objective of optimum utilisation of such species throughout the region, both within and beyond the exclusive economic zone’ (Article 64, UNCLOS). The relevant States have a duty to cooperate either directly or through the appropriate international organisation—typically an RFMO. In regions where no appropriate RFMO exists, the duty to cooperate extends to the establishment of such an organisation and participation in its work (Articles 64 and 118, UNCLOS).

UNFSA

Acknowledging the generality of the UNCLOS framework and the need for more specific guidance, the 1995 *Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks* (UNFSA) (UN, 1995) elaborates on how States must fulfil the duty to cooperate in relation to straddling and highly migratory stocks. The UNFSA also sets out a number of requirements relating to the long-term conservation and sustainable use of these stocks, which may be relevant to the question of how best to respond to the management challenges posed by climate-driven stock redistribution.

Part III of the UNFSA focuses on mechanisms for international cooperation. In particular, it requires States to give effect to their duty to cooperate by participating in, or agreeing to apply the conservation and management measures of, the relevant RFMO (Article 8, UNFSA). The UNFSA provides an extensive list of matters to be agreed upon or implemented by States through an RFMO to fulfil the duty to cooperate, including appropriate conservation and management measures, participatory rights, and the conduct of scientific stock assessments (Article 10, UNFSA). In the particular context of straddling and highly migratory stocks, the UNFSA requires that ‘conservation and management measures established for the high seas and those adopted for areas under national jurisdiction shall be compatible in order to ensure conservation and management of the ... stocks in their entirety’, and States are specifically stated to have a duty to cooperate ‘for the purpose of achieving compatible measures’ in respect of such stocks (Article 7, UNFSA). A number of important factors are also identified as relevant to the determination of compatible measures, including the

‘geographical particularities of the region concerned’ and the dependence of coastal and other States upon the relevant stocks (Article 7, UNFSA).

Many aspects of the UNFSA framework can usefully be applied in the context of climate-driven redistribution of highly migratory fish stocks (see, e.g., Rayfuse, 2019), but none of them directly address the situation of stocks that shift beyond their known geographical distribution in the area under the competence of one RFMO to an area under the management of another RFMO. Although UNFSA does elaborate on how States are to operationalize their duty to cooperate through the mechanism of RFMOs, it does not establish any specific standards or procedures for cooperation between RFMOs. In particular, although Article 7 addresses the compatibility of conservation and management measures adopted for areas under the jurisdiction of coastal States with measures adopted for the high seas, the UNFSA does not consider how to ensure compatibility *between RFMOs* in relation to highly migratory species in adjacent areas of the high seas.

Applying the global fisheries framework in the context of climate change

It is worth noting that the duty to take measures for the conservation and management of stocks on the high seas—or to cooperate with other States in the taking of such measures—is not dependent upon the existence of RFMOs with suitably defined areas of competence. For practical and political reasons, the competence of an RFMO will be restricted in terms of the stocks and/or the geographical area for which it has fisheries management responsibility. However, the duty to cooperate in relation to the living resources of the high seas is a general duty which applies to each individual State, as does the duty to cooperate with regard to highly migratory stocks (Articles 117 and 64, UNCLOS). Further, the duties of a flag State under Article 18 of the UNFSA require it to ensure that vessels flying its flag do not undermine the effectiveness of the conservation and management measures of an RFMO, and that vessels are only authorized to fish on the high seas if the flag State ‘is able to exercise effectively its responsibilities in respect of such vessels under [UNCLOS] and [the UNFSA]’. Consistent with the State-centred approach of international law, each of these provisions points to the ultimate responsibility of the States themselves. If the RFMOs of which the States are members are unable to effectively deal with the conservation and management of tuna stocks that are subject to climate-driven redistribution, then it is up to the relevant coastal and fishing States to make necessary amendments to the structure and operation of those organisations—or to create new ones.

Nonetheless, there are features of the global fisheries framework—and particularly the UNFSA—that could be drawn on to enhance cooperation between RFMOs, and

thereby allow States to fulfill their duty to cooperate under the scenario of shifting fish stocks. For example, Article 13 of the UNFSA requires States to cooperate to strengthen and improve the effectiveness of existing RFMOs and their conservation and management measures, confirming that RFMOs must be subject to ongoing performance reviews. Such a requirement encourages RFMOs to respond to the dynamic requirements of climate change and shifting fish stocks. More generally, cooperation between RFMOs is supported by provisions that strengthen open and informed decision-making, such as Article 12 of the UNFSA, which requires States to ensure that RFMO activities and decision-making processes are transparent, that RFMO meetings are open to representatives from other concerned intergovernmental organisations, and that timely access to the records and reports of the RFMO be granted. These obligations are important to ensure that neighbouring RFMOs can keep abreast of developments in the management of an adjacent fishery that may also affect their members' interests. Another important feature of the UNFSA is the requirement for cooperation in scientific research under Article 14, including to strengthen scientific research capacity in relation to straddling and highly migratory stocks, and to promote the publication and dissemination to any interested States of such research relating to the high seas.

Noting the requirement in Article 8 of the UNFSA that membership of an RFMO is to be open to all States 'having a real interest in the fisheries concerned', the UNFSA also provides some insights as to how an RFMO might proceed if a redistribution of stocks caused additional States to seek membership of that RFMO. Article 11 of the UNFSA provides that in determining the nature and extent of participatory rights for new RFMO members, a number of factors must be taken into account, including 'the needs of coastal States whose economies are overwhelmingly dependent on the exploitation of marine living resources' and 'the interests of developing States from the subregion or region in whose areas of national jurisdiction the stocks also occur'. Such requirements could be important for States who might need to join an RFMO in order to 'chase' access to fish stocks which have moved from the jurisdiction of one organisation to another.

On paper, at least, the framework for fisheries management under UNCLOS and the UNFSA provides a foundation for RFMOs to respond to climate-driven challenges in the management of highly migratory species such as tuna (Pentz et al., 2018; Rayfuse, 2019). States are required to participate in the relevant RFMO if they wish to participate in a particular fishery, to monitor the effectiveness of the RFMO, to share research, and to ensure that RFMO decisions are open and transparent. These features should operate to ensure that all affected States are aware of the status of a fishery, have access to research concerning the impact of climate change on that fishery, and can participate in management and decision-making for those stocks. However, despite having the potential

to respond to climate-related challenges, in practice there are significant limitations on the ability of existing RFMOs to do so (Rayfuse, 2019).

First, there are general limitations arising from the primacy of flag State jurisdiction on the high seas and the international law principle of *pacta tertiis*, under which only the States that have become parties to an international treaty (including an agreement establishing an RFMO) can be bound by the terms of that treaty. Second, there are limitations which arise from the manner in which existing RFMOs have been established—in particular the extent of their geographical and managerial competences, and the potential for their jurisdictional arrangements to no longer be fit for purpose (Pinsky et al., 2018; Rayfuse, 2019). A third set of challenges relate to widely-recognized operational limitations of RFMOs, including: the limited adoption of precautionary measures to regulate the establishment of new fisheries; the limited application of ecosystem-based management principles; and the limitations on decision-making, including the requirement of some RFMOs that all decisions be taken by consensus, and a demonstrably limited ability to take difficult decisions on managing fishing opportunities and addressing the aspirations of new entrants (Pinsky et al., 2018; Engler, 2020). These challenges are all evident in the regional framework that has been established for the conservation and management of highly migratory stocks in the Pacific, through WCPFC and IATTC.

The regional framework: WCPFC and IATTC

WCPFC and IATTC differ significantly in some fundamental characteristics—they have different histories, geographical configurations, and membership—but they have very similar objectives: the conservation and sustainable use of highly migratory stocks in their respective Convention Areas. Importantly, while UNCLOS and UNFSA focus on the rights and obligations of States within RFMOs and do not address inter-RFMO cooperation, the constituent treaties of both organisations specifically recognize the need to cooperate with other RFMOs to achieve their objectives, including in situations where their Convention Area overlaps with that of another RFMO, or where relevant fish stocks also occur in or migrate through the Convention Area of another RFMO. This Section explores the background and context that will underpin future cooperation between WCPFC and IATTC in managing tropical Pacific tuna fisheries, including the key features of these two RFMOs, the measures for adapting to climate change and facilitating inter-RFMO cooperation enabled or required by their constituent instruments, and whether and how such cooperation is currently occurring. Relevant features of both RFMOs, including key provisions, characteristics and measures, are summarized in Table 2.

WCPFC

WCPFC was established in 2004 with the entry into force of the *Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean* (WCPFC Convention) (WCPFC, 2004) and manages fishing for highly migratory species in a large geographical area in the western and central Pacific Ocean (the WCPFC Convention Area) (see Figure 2). WCPFC is characterized by some unique features which distinguish it from other tuna RFMOs—in particular, the geographical configuration of its Convention Area, where approximately 85% of all catches occur within waters under national jurisdiction, and more than 50% of all catches occur within the EEZs of the 17 members of the Pacific Islands Forum Fisheries Agency (FFA) (FFA, 2021), underpinning a strong coastal State influence in the work of the Commission. In contrast to most other tuna RFMOs, none of the key target tuna species managed by WCPFC (skipjack tuna, yellowfin tuna, bigeye tuna and albacore tuna) are currently overfished, nor is overfishing currently occurring (Hare et al., 2021). However, Pacific bluefin tuna, which straddles the northern part of both the WCPFC and IATTC Convention Areas, is currently overfished (Hare et al., 2021; WCPFC, 2021a), as is striped marlin (Ducharme-Barth et al., 2019; ISC, 2019; WCPFC Scientific Committee, 2019) and the oceanic whitetip shark (Tremblay-Boyer et al., 2019).

WCPFC manages tropical tuna stocks primarily through catch or effort limits, or a combination of the two (WCPFC, 2019a; WCPFC, 2021a; WCPFC, 2021b). However, noting the guidance in the UNFSA and the WCPFC Convention on the application of the precautionary approach—including the establishment of precautionary reference points—WCPFC has agreed to develop and implement a harvest strategy approach for each of the key fisheries and stocks in its Convention Area (WCPFC, 2014a; Scott et al., 2022). Harvest strategies set out the management actions necessary to achieve defined and agreed biological, ecological, economic and/or social objectives for fisheries or stocks and will, hopefully, enable WCPFC to take management decisions on key stocks in a consistent, predictable and transparent manner, based on the best available scientific information. As part of this, WCPFC has adopted a biomass depletion-based limit reference point for key tuna stocks of 20% of the biomass that would have been present in the absence of fishing ($20\%SB_{F=0}$)—a metric that is comparable to the maximum sustainable yield (MSY) benchmarks used by other tuna RFMOs, but is considered more robust in relation to key biological uncertainties. WCPFC is also considering depletion-based target reference points for skipjack tuna and South Pacific albacore that imply stock sizes well away from this limit (i.e. stock sizes larger than they would be if fished at MSY) (see, e.g., Cavenagh et al., 2016). Importantly, WCPFC is also developing a ‘multispecies framework’ for harvest strategies, which is intended to account for target species in the WCPO being caught by a mix of fisheries (Scott et al., 2022).

The legal framework underpinning WCPFC appears to contain the necessary principles and powers for its members to take the decisions that are likely to be required to manage the climate-driven redistribution of tuna stocks (see Table 2). However, there are only limited examples of this to date. For example, in 2019, WCPFC adopted a non-binding resolution on climate change, committing the Commission (the principal decision-making body of the WCPFC, comprising representatives of all members) to consider the impacts of climate change on WCPFC’s tuna stocks, and options for addressing these impacts—although it does not mention the possibility that the distributions of some stocks may be shifting eastward in response to ocean warming, nor consider what sort of cooperation might be required with IATTC (WCPFC, 2019b). Article 22 of the WCPFC Convention also specifically requires that the Commission makes suitable arrangements for consultation, cooperation and collaboration with other organisations, including IATTC, and initiates consultation with IATTC with a view to reaching agreement on a consistent set of conservation and management measures for fish stocks that occur in the Convention Areas of both organisations (WCPFC, 2004).

IATTC

Pursuant to the *Convention for the Strengthening of the Inter-American Tropical Tuna Commission Established by the 1949 Convention between the United States of America and the Republic of Costa Rica* (Antigua Convention), which entered into force in 2010 (IATTC, 2010), the IATTC manages fishing for ‘tuna and tuna-like species’ and other species of fish taken by vessels fishing for those species in a large geographical area in the EPO (the IATTC Convention Area) (see Figure 2). In the IATTC, management advice is presented relative to MSY-based reference points. There are some outstanding questions regarding the management status of the key tuna species in the IATTC Convention Area. The status of skipjack in the EPO is not well understood, although IATTC scientists have recently developed an assessment model for the stock (Mauder et al., 2022), and the bigeye stock is generally thought to be fluctuating around MSY biomass and fishing mortality rate reference points (Aires da-Silva et al., 2020; IATTC, 2020). Yellowfin tuna and albacore tuna are not assessed to be overfished or subject to overfishing (ISSF, 2022). However, IATTC has dedicated very little of its management resources to the south Pacific albacore stock.

In contrast to WCPFC, the IATTC Convention Area primarily covers high seas rather than EEZs, due to the contiguous coastline in the Americas and the relative lack of oceanic islands. However, a bigger contrast between the two RFMOs is the way that their fisheries are managed. Although there are secondary policies in place, IATTC manages its tropical

TABLE 2 Key features, provisions and measures of WCPFC and IATTC.

WCPFC (Articles refer to the WCPFC Convention)	IATTC (Articles refer to the Antigua Convention)	
Convention Area		
The WCPFC Convention Area comprises all waters of the Pacific Ocean extending south from the Australian continent along 141°E to the southern boundary at 60°S, then north at 130°W to 4°S, and thence north along 150W. It does not have a defined boundary in the north or north-east (see Figure 2).	The IATTC Convention Area is located between 50°N and 50°S, bounded by the coastline of North, Central and South America in the east, and extending to 150°W in the west (see Figure 2).	
Catch		
The WCPFC Convention Area contains the world's most valuable tuna fishery, which provides approximately 52% of the global tuna catch (McKinney et al, 2020 ; Williams and Ruaia, 2021 ; ISSF, 2022).	The tuna fisheries in the IATTC Convention Area are significantly less productive than those managed by the WCPFC, producing around just 13% of the global tuna catch (ISSF, 2022).	
Members and Cooperating Non-Members (CNMs)		
WCPFC Member only	WCPFC and IATTC Member	IATTC Member only
Australia, Cook Islands, FSM, Fiji, Marshall Islands, Nauru, New Zealand, Niue, Palau, PNG, Philippines, Samoa, Solomon Islands, Tonga, Tuvalu	Canada, China, European Union, France, Japan, Kiribati, Korea, Chinese Taipei, United States, Vanuatu	Belize, Colombia, Costa Rica, Guatemala, Mexico, Peru, Venezuela
IATTC Member and WCPFC CNM		
Ecuador, El Salvador, Nicaragua, Panama		
WCPFC CNM only	WCPFC and IATTC CNM	IATTC CNM only
Curacao, Thailand, Vietnam	Liberia	Bolivia
Structure of the RFMO		
The work of the WCPFC is directed and overseen by a Commission (Articles 9 and 10), supported by subsidiary bodies including the Scientific Committee (SC), the Technical and Compliance Committee (TCC), and the Northern Committee (NC), which makes recommendations in relation to stocks which occur in the area north of 20°N (Article 11).	The work of the IATTC is directed and overseen by a Commission (Articles VI and VII), supported by a Committee for the Review of Implementation of Measures Adopted by the Commission (Article X) and a Scientific Advisory Committee (Article XI).	
Scientific Advice		
The WCPFC Convention specifically recognizes the importance of adequate scientific information (Article 5(b)) and provides for the Commission to engage the services of scientific experts to provide the necessary information and advice (Article 13). Scientific services are provided by the Oceanic Fisheries Programme of the Pacific Community (SPC-OFP), and additional advice in relation to northern stocks is provided by the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC).	The Commission is specifically required to promote, carry out and coordinate scientific research on the stocks and species covered by the Antigua Convention—including 'the effects of natural factors and human activities on the populations of these stocks and species'—and adopt measures based on the best scientific evidence available (Article VII). The IATTC has internal scientific staff to provide information, advice and recommendations to the Scientific Advisory Committee and the Commission (Article XIII), as well as field offices in a number of countries and its own research laboratory, based in Panama. Additional advice in relation to northern stocks is provided by the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC).	
Conservation and Management Principles		
Reflecting the developments incorporated in the UNFSA, the WCPFC Convention incorporates an expanded range of conservation and management principles (Article 5), specific guidance on the application of the precautionary approach (Article 6 and Annex II), and rules for ensuring compatibility between measures adopted for the high seas and for areas under national jurisdiction (Article 7).	The Antigua Convention does not incorporate the general principles for conservation and management established in Article 5 of the UNFSA. It does provide for the application of the precautionary approach (Article IV) and the establishment of compatible measures for the high seas and areas under national jurisdiction (Article V), but these provisions are less detailed than those in the UNFSA.	
Special Requirements of Developing States		
Article 30 of the WCPFC Convention addresses the special requirements of developing States. It provides that the Commission shall take these into account in giving effect to the duty to cooperate through the adoption of conservation and management measures and notes the vulnerability of developing States which are dependent on the exploitation of living marine resources.	The Antigua Convention does not include the specific provisions on the requirements of developing States contained in Article 24 of the UNFSA, although it does envisage financial and technical cooperation to assist developing members of the Commission (Article XXIII).	
Measures to Address Climate Change		
In 2019, the WCPFC adopted a non-binding resolution on climate change, which commits the Commission to considering the impact of, and options for addressing, climate change on the WCPFC's tuna stocks (WCPFC 2019a). The WCPFC has supported the continuation of large-scale tagging experiment work led by the Oceanic Fisheries Programme of the Pacific Community (SPC-OFP) (the scientific services provider for the WCPFC), recognizing that it is necessary to inform stock assessments of tropical tunas in the WCPO (Hare et.al., 2021).	The IATTC Strategic Science Program incorporates some projects on climate change, including Project N.2.a on developing models of the effects of climate change on pre-recruit life stages of tropical tunas and Project N.2.b on supporting climate-ready and sustainable fisheries: using satellite data to conserve and manage life in the ocean and support sustainable fisheries under climate change. The IATTC's Observer Programme uses a combination of national and IATTC	

(Continued)

TABLE 2 Continued

WCPFC (Articles refer to the WCPFC Convention)	IATTC (Articles refer to the Antigua Convention)
<p>The WCPFC's Regional Observer Programme, which uses existing national and subregional observer programmes of WCPFC members, provides information concerning the catch composition of the main WCPO tuna fisheries (Hare et al., 2021). The WCPFC has also been using the Spatial Ecosystem And Population Dynamics Model (SEAPODYM) (Lehodey et al. 2014) framework to investigate how climate change could affect the distribution and abundance of tropical tunas and albacore tunas.</p>	<p>Secretariat placements, and similarly provides information concerning the catch composition of the main EPO tuna fisheries.</p>
Measures Giving Effect to Cooperation with the other RFMO	
<p>WCPFC CMM 2021-02 on Conservation and Management Measure for Pacific Bluefin Tuna provides that the WCPFC Executive Director must communicate the measure to the IATTC Secretariat and its Parties who fish for Pacific bluefin tuna in the EPO, with a request that they take equivalent measures. WCPFC members are also 'encouraged to communicate with and, if appropriate, work with the concerned IATTC contracting parties bilaterally' (WCPFC, 2021b).</p> <p>WCPFC CMM 2019-03 on Conservation and Management for Swordfish recognizes 'the need for both WCPFC and IATTC to adopt conservation and measures to provide for the sustainable management of swordfish stocks across the Pacific Ocean', although in practice swordfish is essentially unmanaged by IATTC (WCPFC, 2009b).</p> <p>WCPFC CMM 2019-03 on North Pacific Albacore goes further, tasking the WCPFC Executive Director to communicate the WCPFC measure to the IATTC with a request that the two Commissions engage in consultations with a view to adopting uniform conservation and management measures and agreement on any reporting or other measures needed to ensure compliance (WCPFC, 2019b).</p>	<p>Resolution C-21-05 Measures for the Conservation and Management of Pacific Bluefin Tuna in the Eastern Pacific Ocean recognizes that the stock of Pacific bluefin tuna is caught in both the WCPO and the EPO, and that conservation and management measures by WCPFC and IATTC should be considered 'in cooperation between the two RFMOs taking into account historical and future projected proportional fishery impacts on SSB between fisheries in the EPO and fisheries in the WCPO'. Assessments prepared by the IATTC shall take into account conservation and management measures adopted by the WCPFC, and that in revising management measures for Pacific bluefin tuna, the Commission must consider outcomes of the Joint Working Group (IATTC, 2021b).</p> <p>IATTC Resolution C-22-04 states that the Commission 'shall promote compatibility, starting with the definition of "reference points", between the harvest strategy adopted through this Resolution, and any future harvest strategy adopted in the WCPFC with respect to North Pacific albacore' and tasks the Director to communicate this Resolution to the WCPFC Secretariat (IATTC, 2022c).</p>

tuna purse-seine fleets almost entirely via a seasonal closure, during which vessels must be in port. The length of the closure is determined by reference to the tropical tuna stock with most concerning status, and additional closure days are assigned to individual vessels based on their catch of juvenile bigeye tuna (IATTC, 2021a). IATTC is also unique among the tuna RFMOs in that there are three competing fishing strategies among purse-seine vessels: fishing on floating objects; fishing on dolphin-associated schools; and fishing on unassociated schools. While tensions in other RFMOs may be between purse-seine and longline fleets, or between coastal States and distant water fleets (Azmi and Hanich, 2021), tensions within IATTC are dominated by disagreements between the purse-seine fleets that fish using fish aggregating devices (FADs) and those that target dolphin-associated schools. Longline fleets are only allocated a TAC for bigeye tuna, with their catch otherwise essentially unmanaged.

Like the WCPFC Convention, the Antigua Convention includes principles and powers that enable (and arguably require) IATTC to take effective and pro-active steps to ensure the sustainable management of Pacific tuna stocks in the face of climate change (see Table 2). However, also like WCPFC, there is limited evidence of progress in this respect (Pentz and Klenk, 2020). IATTC has incorporated climate change into its 5-year Strategic Science Plan (2019-2023), which includes work aimed at understanding the effect of long-term climate drivers (regime shifts) on the abundance of tropical tunas, but has not yet adopted any other measures which specifically relate to the impacts of climate change, or consider the sort of cooperation

with WCPFC which might be required to address it. Article XXIV of the Antigua Convention also specifically provides for IATTC to cooperate with other RFMOs, including in the situation of overlapping Convention Areas, and where fish stocks migrate through areas under the purview of IATTC and another RFMO.

The current state of cooperation

Cooperation between WCPFC and IATTC has long been important, because they manage the same species in Convention Areas which not only adjoin but overlap, in an area between the western boundary of IATTC at 150°W, and the eastern boundary of WCPFC at 130°W (see Figure 2). The history of this overlap is briefly explored in discussion papers prepared by the Executive Directors of IATTC and WCPFC, which note that 150°W was used as the western boundary of IATTC by scientists as early as 1972, and as the eastern boundary of the WCPO in reports and assessments on yellowfin tuna prepared by the South Pacific Commission in the 1990s (WCPFC, 2011a; IATTC, 2012a). During the negotiation of the WCPFC Convention, this approach was followed in setting the northern segment of WCPFC's eastern boundary (north of 4°S) at 150°W, but the southern part of the eastern boundary (between 60°S and 4°S) was placed at 130°W to ensure that the entirety of the Kiribati and French Polynesian EEZs were included in the WCPFC Convention Area (WCPFC, 1999). A report on the progress of the negotiations prepared by the University of Hawaii's Pelagic

Fisheries Research Program in 1999 concluded that: ‘Although less than ideal from an ecological point of view, the area is probably satisfactory for coping with fisheries for skipjack, yellowfin tuna, and south Pacific albacore in the near term, but many biologists might question its suitability in the longer term, particularly for bigeye and bluefin tunas and swordfish’ (PFRP, 1999).

Cooperation between WCPFC and IATTC has been underway in a range of guises for many years—although more in form than in substance. The two organisations have developed three formal instruments on cooperation:

- a 2006 Memorandum of Understanding, in which they agree to consult and cooperate in respect of matters of common interest including the exchange of data and information, research on stocks and species of mutual interest (including Pacific-wide stock assessments), and conservation and management measures for stocks of mutual interest (WCPFC, 2006a);
- a 2009 Memorandum of Cooperation on the Exchange and Release of Data (MOC on Data), which underpins cooperation on Pacific-wide stock assessments on tunas and sharks and an annual exchange of data and information between the IATTC and SPC-OPF (which is the Scientific Services Provider to the WCPFC) (WCPFC, 2009a); and
- a 2011 Memorandum of Cooperation on the Cross-Endorsement of Observers (MOC on Observers), which provides for approved observers who meet the necessary training requirements to be cross-endorsed to operate on vessels that fish on the high seas in both Convention Areas and the overlap area (WCPFC, 2011b).

A meeting between the Secretariats was also established to facilitate cooperation between the two RFMOs (the ‘WCPFC-IATTC Consultative Meeting’), which met on four occasions in 2007 and 2008.

While there have not been any further meetings of the WCPFC-IATTC Consultative Meeting since 2008, in 2011 the Executive Directors of both RFMOs met to discuss measures for managing fishing in the overlap area. This discussion produced five options for consideration by WCPFC and IATTC (IATTC, 2012a):

1. management of the overlap area assigned to one RFMO only, through an MOU;
2. management of the overlap area assigned by gear type, with IATTC managing the purse-seine fishery, and WCPFC managing longlining;
3. establishment of a ‘special management area’, where an agreed set of management measures would be applied;

4. application of measures by both Commissions, with vessels from the WCPFC Register fishing under WCPFC rules, vessels from the IATTC Register fishing under IATTC rules, and vessels registered with both RFMOs selecting and advising under which Commission’s rules they wished to fish; and
5. establishment of a working group to consider longer-term options for management of tuna in the Pacific Ocean basin.

The RFMOs agreed that option 4 was the most practical in the short term, but that a longer-term process should be established to explore avenues for managing tuna stocks in the entire Pacific Ocean, as proposed in option 5 (IATTC, 2012b; WCPFC, 2013). The first (short term) part of this decision is commonly reflected in the conservation and management measures of both organisations, but no progress appears to have been made on the second (long term) proposed avenue for cooperation.

In recent years, the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC), which provides scientific advice to the WCPFC and IATTC for northern stocks, has facilitated scientific collaboration on Pacific-wide stock assessments on tunas, billfishes and sharks, many of which have a shared distribution between the IATTC and the WCPFC Convention Areas. In 2015, the WCPFC Northern Committee (NC), which makes recommendations in relation to stocks which occur mostly in the WCPFC Convention Area north of 20°N, requested WCPFC to arrange a joint meeting with IATTC on the management of Pacific bluefin tuna. This led to the establishment of the IATTC-NC Joint Working Group on Pacific Bluefin Tuna Management (Joint Working Group), which has convened annually since 2016, and makes recommendations and drafts proposals for each RFMO with agreement that there will be few or no alterations when the proposals are put forward for final adoption at each Commission. The annual meetings of the Joint Working Group include all participants in Pacific bluefin tuna fisheries, who receive the scientific advice and stock assessment updates from the ISC and develop harmonized draft proposals for conservation measures and harvest strategies. At the Joint Working Group’s second meeting in 2017, a rebuilding plan was negotiated for the highly depleted, single population of this species, requiring both RFMOs to end the overfishing that had resulted in part from independent management approaches by each RFMO (Madigan et al., 2017). In 2018, the Joint Working Group also established a Technical Working Group to progress the development of a draft Catch Documentation Scheme for Pacific Bluefin tuna, which has so far met three times. The success of the cooperation through the Joint Working Group is reflected in the adoption of the aforementioned rebuilding plan, the resulting improvement

in stock status (ISC, 2022), and the negotiation of new management activities by both RFMOs in 2021 (IATTC, 2021a; WCPFC, 2021a).

It is important to note that negotiations on management of tropical tuna species are incredibly difficult, and sometimes break down. For example, between December 2020 and October 2021, IATTC required five separate meetings to adopt a new tropical tuna measure based on the 2020 stock assessments, including an emergency session in late December to avoid tropical tuna fisheries becoming unmanaged on 1 January 2021. Similarly, from 2017 to 2018, several Commission meetings were required to address outstanding issues, with adopted measures abandoned and replaced within only a few months. Despite these difficulties, IATTC has a three-year measure in place to manage these fisheries until the end of 2024, with a mandate to produce a management strategy evaluation and a harvest strategy for bigeye tuna to be considered for adoption in 2024 and implementation in 2025. WCPFC has also had trouble negotiating management measures for the key tropical tuna species. In particular, WCPFC has been unable to reach consensus on binding high seas limits on all WCPFC members for tropical tunas, while avoiding a disproportionate burden on developing States, and has essentially rolled over the same management measure year-on-year with minor amendments. The challenge of negotiating management measures was exacerbated by COVID. Despite inter-sessional negotiations, WCPFC extended the application of the management measures adopted for 2020 to apply through 2021, and then eventually rolled these over in largely unchanged form for 2022. While the commitment of both RFMOs to developing harvest strategies should improve the situation, these examples suggest that decision-making on management measures will be one of the most challenging areas for cooperation between WCPFC and IATTC.

The legal frameworks of both RFMOs envisage, enable and encourage cooperation between WCPFC and IATTC on relevant issues, and some steps have been taken to put meaningful measures into place—in particular, the MOC on Data, the MOC on Observers, the decision regarding vessels operating in the overlap area, and the Joint Working Group. However, after more than 20 years—and with the exception of collaboration in scientific work—there is still limited evidence of real and effective cooperation between these organisations on the actual management of tropical tuna fisheries.

Options for enhancing cooperation and collaboration

Notwithstanding the limited extent of cooperation between WCPFC and IATTC, to date their measures to sustain the tuna stocks in their respective (and overlapping) areas of jurisdiction have, with some exceptions, been relatively successful. However,

the predicted shifts in distribution of tropical tuna stocks in the Pacific Ocean Basin suggest that a more strategic approach to the form and substance of cooperation between these two RFMOs will be needed to ensure successful conservation and management of these resources into the future. In this Section, we provide a detailed analysis of the issues that should be considered in developing a model for such cooperation.

We start from the premise that the framework for cooperation between WCPFC and IATTC should apply, adapt and—where necessary—develop the principles established in UNCLOS, UNFSA, and the constituent Conventions of the two RFMOs, to identify and address the types of issues that are likely to arise as a result of climate-driven redistribution of tuna stocks. In order to understand how these principles and policies might arise and be applied in practice in a future scenario, we consider four key areas of RFMO activity: governance; science and research; conservation and management; and compliance and enforcement. By considering the ramifications of climate-driven redistribution of tuna stocks for each of these areas, we can identify options for WCPFC and IATTC to actively engage and develop an effective framework for future cooperation.

Governance and institutional issues

The starting point for considering enhanced cooperation between WCPFC and IATTC is their governance—the legal framework within which they operate, and the mechanisms and methods by which they act and take decisions. The first aspect of governance that could be addressed is a review of the competence of each RFMO as a basis for agreement on how best to allocate responsibility to meet their member States' obligations under UNCLOS and the UNFSA in the context of future stock distributions. For WCPFC and IATTC, competence is defined both spatially, in terms of an 'area of application', as well as biologically, in terms of the stocks that are the focus of management. These jurisdictional requirements are cumulative, in that competence depends both upon the existence of a relevant stock *and* its presence in the relevant Convention Area; that is, neither Convention contemplates management of a particular stock once it travels outside the Convention Area. Defining the operation of the RFMOs in this way mimics both the essential strength and fundamental weakness of the regime of maritime zones under UNCLOS: the clear demarcation lines provide certainty for State rights and responsibilities, but do not reflect biological limits and are therefore unlikely to be the most effective basis for sustainable conservation and management. Amending the constituent instruments of WCPFC and IATTC to address this weakness is not a realistic option. A more realistic solution is to identify the fish stocks that are most likely to be impacted by climate-driven redistribution and, reflecting the commitments to inter-RFMO cooperation already contained in

each RFMO agreement, agree on how best to manage each stock within the existing framework.

The second aspect of governance that should be addressed is to formally elevate the prominence of climate change impacts on fisheries management within the work of each RFMO generally, such as through a dedicated working group and consideration at the annual Commission meeting. Both RFMOs have made progress in this area, but to a large extent climate change is still treated as peripheral rather than integral to their management of fisheries. In this respect, and at a minimum, cooperation between the RFMOs needs to be a substantive standing item on the Commission meeting agenda for each RFMO, with a contribution invited from a representative of the other organisation. While Commission meeting agendas are already crowded and contested, the issue of cooperation will only increase in importance over time as climate-driven stock redistribution occurs—indeed, the agenda item could include a specific focus on cooperation needed to address climate-related impacts on Pacific tuna fisheries. Developing a practice of substantive and open discussion across the RFMOs will strengthen their ability to respond to change.

As outlined below, science and research will play a key role in supporting the ability of the two RFMOs to effectively manage the climate-driven redistribution of tuna stocks, and it will be important to ensure that governance procedures support them in satisfying their data requirements for effective decision-making. In particular, cooperation will be needed to establish effective procedures for timely and accurate collection and reporting of data, for sharing data between bodies, and for appropriately maintaining confidentiality. Cooperation between science providers will be particularly important and the two RFMOs should look for ways in which cooperation and collaboration can be enhanced. To this end, the Commissions will need to implement mechanisms for formalizing cooperation between IATTC and WCPFC at the operational level. This is not a new recommendation: during the preparatory conference for the establishment of WCPFC, a joint working paper produced by the IATTC and WCPFC Secretariats included recommendations about procedures for sharing information on scientific and management issues, and the creation of a permanent working group to enhance cooperation through information sharing and dialogue (WCPFC, 2002; IATTC, 2005). A similar recommendation was made in option 5 of the 2011 paper produced by the Executive Directors (as discussed above).

Finally, the prospect of fish stocks shifting into the jurisdictional domain of another RFMO might lead to some difficult questions about RFMO membership. In particular, some RFMO members might be motivated to pursue membership of another RFMO to ensure continued access to the fishery. In theory there is no impediment to a State joining more than one RFMO, and in the context of WCPFC and IATTC, there is already a substantial overlap in participation across the two organisations (see Table 2). However, the possibility of additional States seeking to

join one or the other of these RFMOs highlights the importance of the rules in each organisation as to whether—and how—to accommodate new entrants. In particular, if fish stocks are projected to move eastward, then members of WCPFC might seek to join IATTC and ‘follow the fish’. In this event, the provisions of the Antigua Convention on accession to the treaty become particularly important.

Aside from Parties to the 1949 Convention which originally established IATTC, and Parties with a coastline bordering the Convention Area, accession to the Antigua Convention is generally open to new members only if their vessels fish for stocks covered by the Convention (following consultations with the existing Parties), or if they are otherwise invited to become members on the basis of a decision by the existing Parties (Articles XXVII and XXX, Antigua Convention). This regime gives considerable control to the existing members in determining whether or not to allow new members—although it may be difficult to reconcile with Article 8 of UNFSA, which provides that ‘States having a real interest in the fisheries concerned may become members of such organisation’, and further, that ‘the terms of participation in such organisation or arrangement shall not preclude such States from membership or participation; nor shall they be applied in a manner which discriminates against any State or group of States having a real interest in the fisheries concerned’. This might, by extension, also raise questions about practice under the WCPFC Convention, which provides in Article 35 that, beyond the States which participated in the negotiation of the Convention, other States may only become party by a consensus decision of all Parties. To date, such consensus has not been forthcoming, despite explicit requests to join from past or present co-operating non-members including Belize, Ecuador, El Salvador, Mexico, Panama and Vietnam (WCPFC, 2017a). There is also the possibility of additional States seeking co-operating non-membership of IATTC.

However, as Molenaar (2019) points out, even if these questions are satisfactorily resolved, neither membership nor co-operating non-membership guarantees access to participatory rights, or to any particular allocation of resources. For example, even though the North Atlantic Fisheries Organisation (NAFO) is an ‘open’ RFMO, to which any state may be become party, in order to ‘guide the expectations of future new members with regard to fishing opportunities in the NAFO Regulatory Area’, NAFO indicated as long ago as 1999 that new members ‘should be aware that presently and for the foreseeable future, stocks managed by NAFO are fully allocated, and fishing opportunities for new members are likely to be limited, for instance, to new fisheries’ (NAFO, 1999). These issues will be even more complicated in a situation where the fishing opportunities in question relate to stocks that were previously under the jurisdiction of another RFMO (and in some cases under the sovereign rights of coastal State members of that RFMO). In this case, the meaning of ‘real

interest' under UNFSA might need to be interpreted in a way that appropriately recognizes a new category of issues, such as States in whose waters the stock previously occurred, or even the loss of licensing revenue.

Science and research

As outlined above, in the context of scientific work, there is already significant collaboration between the two RFMOs, including through tagging programmes, sharing of data, and joint Pacific-wide stock assessment analyses. However, there are a range of areas where further cooperative work could be undertaken to ensure that management of Pacific Ocean tuna stocks continues to be effective in the face of climate change.

First, it will be imperative to develop a clearer understanding of the nature and evolving distributions of key tuna stocks within the Pacific Ocean. A recent review of the existing knowledge about the spatial stock structures of skipjack, yellowfin, bigeye and albacore tunas indicates that each of these species is likely to consist mainly of one large (panmictic) population spanning the WCPO and EPO with multiple overlapping sub-populations due to genetic isolation by distance, or possibly several smaller, self-replenishing populations (Moore et al., 2020a). The review infers that WCPFC and IATTC may be sharing stocks of each tuna species to a greater degree than previously realized—something that needs to be determined using the methods described by Moore et al. (2020b). The extent to which cooperative stock assessment and management approaches by the two RFMOs may benefit from an improved understanding of the stock structure of each species will depend on the spatial complexity of stocks, and the nature of mixing within and between stocks. If the stock structure of a tuna species is panmictic with genetic isolation by distance, Pacific-wide processes would need to be considered for stock assessments, but any changes to current management practices are likely to be limited. Conversely, if a tuna species consists of multiple stocks, more complex and spatially explicit assessment frameworks may be required for those stocks that span the Convention Areas of both RFMOs (Moore et al., 2020a).

Identifying the spatial structure of each tuna species will set the stage for fine-tuning the application of jurisdictional approaches to tuna fisheries (Kittinger et al., 2021). Jurisdictional approaches integrate market-based and governance incentives at relevant ecological and political scales to drive fisheries sustainability and value creation across entire seafood production geographies. The member States of the Parties to the Nauru Agreement (PNA) are already applying these principles in the WCPO to manage fishing effort through their 'Vessel Day Scheme' and associated marketing initiatives (Agorau, 2020). The improved understanding of tuna stock structure across the Pacific Ocean basin will identify the stakeholders for each stock and the scope for considering

additional collaborative arrangements to sustain and add market value to catches.

Ultimately, appropriate cooperative management approaches to the climate-driven redistribution of tuna resources will depend on the extent to which stocks become or remain transboundary. Little to no change may be required for panmictic stocks with genetic isolation by distance beyond enhancing monitoring, control and surveillance (MCS) measures and associated enforcement in high seas areas, and catering for the disproportionate economic impacts imposed on some Pacific SIDS due to the expected eastward shifts in distribution. More complex stock structures are likely to invoke the need for more diverse and flexible management and monitoring arrangements, particularly for shifting stocks. For example, new, compatible monitoring programmes, harvest strategies and management measures may need to be evaluated for a stock previously limited to the WCPFC Convention Area that spans the jurisdictions of both RFMOs following redistribution. The success of the PNA Vessel Day Scheme in dealing with the effects of the El Niño Southern Oscillation (ENSO) on purse-seine catches over a domain of 13 million km² (Agorau et al., 2018; Clark et al., 2021) points to the benefits likely to result from increased compatible management efforts by WCPFC and IATTC due to climate change.

A second area for scientific cooperation is sampling. The sampling approaches required to identify the nature and distribution of tropical tuna stocks within the combined Convention Areas of WCPFC and IATTC was assessed in 2018 (Moore et al., 2020b). Key features of the recommended sampling designs included co-ordinated, broadscale collection of samples across the distribution of each species; targeting adults in spawning condition; and repeated sampling of the same geographical areas over time to assess stability of observed patterns of stock structure. A multidisciplinary approach to stock identification, based on genetic analysis, taxonomy of parasite loads, and otolith microchemistry, was also recommended.

Third, investments are needed to improve the modelling for how each identified tuna stock is likely to respond to climate change. WCPFC has been using the Spatial Ecosystem And Population Dynamics (SEAPODYM) modelling framework (Lehodey et al., 2014) to investigate how climate change could affect the distribution and abundance of tropical tunas and albacore tunas. SEAPODYM is particularly well suited for simulating the effects of climate-driven changes to the physical, chemical and biological features of the Pacific Ocean on the distribution of tuna (Lehodey et al., 2008; Senina et al., 2008; Senina et al., 2020a). However, further improvements over past and recent SEAPODYM simulations and analyses (Lehodey et al., 2011; Lehodey et al., 2013; Lehodey et al., 2015; Bell et al., 2021) are needed to reduce uncertainty. These improvements should focus on: increasing the spatial resolution of the climate simulations model (currently operating at 2° of latitude and longitude); revising model parameter estimates at this higher

resolution using updated fishing and tagging data to better inform tuna movement and habitat parameters (Senina et al., 2020b); and assessing key model uncertainties, including physical (e.g., influence of the Interdecadal Pacific Oscillation on the onset of accelerated ocean warming), biogeochemical (e.g., parameterisation of the microbial loop), or biological (e.g., effect of ocean acidification on mortality of larval stages, Frommel et al., 2016; Nicol et al., 2022) factors. The two RFMOs can also play a role in reducing uncertainty in ecosystem and tuna modelling through enlisting the assistance of industrial fishing vessels operating within their jurisdictions to collect additional data and information needed to verify and inform the modelling.

Fourth—and building on some of the options suggested above—stock assessments for tuna can be adjusted where appropriate to incorporate the improved understanding of stock structure and the projected responses of stocks to climate change. Most Pacific tuna stock assessments to date have generally been RFMO-specific, although Pacific-wide assessments have been performed to test the ‘sensitivity’ of assessed stock status to the RFMO-specific stock assumption (Hampton and Maunder, 2005; McKechnie et al., 2015) or to meet managers’ specific requests (Castillo Jordán et al., 2021). In these cases, the spatial structure of pan-Pacific assessments was developed so that RFMO boundaries were maintained, and RFMO-specific results could be provided. These results have proved to be relatively robust to the regional/Pacific-wide assumption (Hampton and Maunder, 2005; McKechnie et al., 2015). However, biological parameters such as growth, which can vary from the west to the east Pacific (Hampton, 2017), must currently be assumed to be constant across space within assessments. Thus, the parameter values used may correspond to those from either the western or eastern Pacific. This means that RFMO-specific stock assessments (rather than Pacific-wide assessments) may be more robust to this spatial heterogeneity and are currently generally suitable for management of WCPO and EPO ‘stocks’. Nevertheless, close monitoring of any changes to stock structure relative to those structures presently used for stock assessments, and climate-driven redistribution of stocks, will be increasingly important in informing the need for enhanced scientific collaboration between RFMOs.

Finally, the focus on development of harvest strategies for tuna stocks by WCPFC and IATTC will also benefit from integration of information from climate modelling (see, e.g., Merino et al., 2019). Harvest strategies are aimed at enhancing stock sustainability and the benefits gained from the fishery. They involve the implementation of tested and pre-agreed ‘harvest control rules’ as part of a management procedure to improve the responsiveness of management decision-making to changes in the assessed status of stocks (Butterworth, 2007; Rademeyer et al., 2007). The performance of management procedures is tested within a simulation framework prior to implementation to identify which procedures best achieve the

objectives of stakeholders in the fishery and are robust to the uncertainties inherent in our understanding (Punt et al., 2016). Harvest strategies are likely to be reviewed at timescales shorter than those currently projected for the substantial impacts of climate change on Pacific tuna. Ongoing improvements to the modelling of how climate change may alter stock distribution, and fish movement and biology, will allow these uncertainties to be re-examined as harvest strategies evolve. In turn, monitoring the actual impacts of climate change on the stock and fishery over time will signal an ‘exceptional circumstance’ where those changes fall outside the ranges of uncertainty against which a harvest strategy was tested, and hence whether that strategy needs to be revisited (de Moor et al., 2022). It will also allow review of the ability of selected management procedures to continue to achieve the objectives of stakeholders in the face of regional climate impacts (Merino et al., 2019). In short, harvest strategies informed by climate modelling would be expected to provide each RFMO with a framework to adjust overall catch and effort limits to ensure sustainable management within their jurisdiction, and to adjust these limits if fish are progressively re-distributed into other jurisdictions in ways that should enable a shared stock to be managed sustainably.

Conservation and management

As described in their constituent instruments, the central objective of both WCPFC and IATTC is to ensure the long-term conservation and sustainable use of highly migratory stocks in the Pacific Ocean through the adoption of appropriate conservation and management measures (WCPFC, 2004; IATTC, 2010). This necessarily includes setting appropriate limits on fishing. Where stocks are overfished or where overfishing is occurring, or where there is a risk of exceeding limit or threshold reference points or moving away from target levels, effective conservation and management of fish stocks should include a cap in some form, whether defined as catch volume, effort or capacity. These controls should be applied across the entire range of the stock or sub-stock (Article 7(2), UNFSA), guided by harvest strategies based on the best scientific evidence available and applying a precautionary approach. Importantly, catch or effort limits for highly migratory stocks must be compatible across jurisdictional boundaries—not only between EEZs and high seas, as established in Article 7 of the UNFSA, but also between the Convention Areas of different RFMOs. The practicalities of setting compatible actions are complex and, in reality, represent the tip of a regulatory iceberg, each element of which is open to debate and negotiation: how are they to be defined? How and to whom are they to be allocated? What are the rules of the game once catch or effort limits have been allocated, and how are they (and allocations) to be adjusted over time to reflect new information?

A first area for cooperation between WCPFC and IATTC might be to consider how to define catch or effort limits adopted by the two organisations in a way that ensures they are compatible. This will be particularly important as the ranges of tropical tuna stocks increasingly straddle the two Convention Areas. At present, WCPFC manages its key tropical tuna stocks mainly through a combination of catch and effort limits,¹ whereas IATTC primarily relies on closures. If management actions cannot be defined using the same metrics, they should at least be translatable between RFMOs to ensure that they are directed toward achieving a shared objective for the stock. Without a common language between the two RFMOs, members are unlikely to know whether the measures they have adopted can achieve the desired shared management and conservation goals.

A related issue for consideration is around the management benchmarks used within the two RFMOs. Given their differing approaches in terms of management targets and likely differing acceptable risks of breaching limit reference points, the results of the research described above will be important to identify whether adaptation is necessary.

Ultimately, the two RFMOs will need to come to some form of agreement that enables the adoption of sustainable and equitable catch or effort limits. This could include the adoption of harvest strategies for all shared stocks, or stocks that are likely to shift across RFMO boundaries over time. As noted above, WCPFC and IATTC may therefore need to consider the role of harvest strategy development in providing a tool to assist in managing potential future shifts in tuna resources. Although they are at different stages in the process, both RFMOs have already decided to develop harvest strategies for one or more of the stocks under their jurisdiction. Thus, there should be scope for aligning some aspects of these strategies—whether in relation to the management objectives or the actions to be taken in the face of specified situations—to help ensure that foreseeable levels of change can be managed as consistently, predictably and as transparently as possible within the scope of each RFMO's management framework.

The most challenging area for cooperation between WCPFC and IATTC will almost certainly be in respect of the allocation of fishing opportunities. Allocation is already a complex and often divisive task, and the level of difficulty will only be increased by the climate-driven redistribution of stocks to different geographic areas—not only in terms of movement from one RFMO to another, but in terms of movement from EEZs, where coastal States have sovereign rights, to areas of high seas, where all States have (in theory at least) the freedom to fish. The failure to equitably allocate resources has been recognized as one of the

greatest threats to the stability of fisheries management regimes (Lodge et al., 2007), and significant cooperation will be needed to ensure that fishing opportunities continue to be allocated equitably in light of climate-driven stock redistributions, not only between parties to one RFMO or the other, but across both RFMOs. In this respect, questions of the transferability of rights will play an important role in ensuring that allocations to 'losing States' remain valuable and exercisable as stocks shift to the east.

In this process, consideration will need to be given to all the normal criteria used in allocation—the sovereign rights of coastal States, the freedom of fishing of all States on the high seas, the extent to which States comply with their responsibilities, the natural distribution of the stocks, the catch histories of all States, the special requirements of developing States and special circumstances of SIDS, considerations of food security and economic dependence on the resources, and development aspirations (Seto et al., 2021). But more than that, the RFMOs will need to cooperate to ensure that these criteria are considered in light of the underpinning (and overarching) role of climate change in driving the redistribution of tuna stocks, and in a way that gives meaningful effect to principles of intra-generational and inter-generational equity. Indeed, in addition to the 'special requirements' and 'special circumstances' provisions in Articles 24 and 25 of UNFSA, the principle of common but differentiated responsibilities which is laid out in the 1992 *Rio Declaration on Environment and Development* (UN, 1992a) and embodied in the *United Nations Framework Convention on Climate Change* (UNFCCC) (UN, 1992b) will also be relevant. In effect, a key objective of cooperation between the RFMOs in this context should be to find a way to preserve the rights and interests of all States as they were prior to the climate-driven changes that are coming.

This idea is not entirely new in this region. For example, at the 2019 WCPFC Commission Meeting, Korea noted anecdotal evidence that tropical tunas were aggregating in the high seas more frequently compared to past years, and expressed concern that its industry would suffer if Korea was unable to access sufficient fishing opportunities in the high seas. In this context, Korea suggested that the WCPFC explore the possibility of allowing States to use 'vessel days purchased under bilateral fishing arrangements in the high seas, while making sure that such a system does not negatively affect the sovereign rights or aspirations of SIDS' (WCPFC, 2019c; Hanich et al., 2021). As the latter part of the previous sentence notes, this has important implications not only for flag States who fish in EEZs, but for coastal States who lose resources from their EEZ due to climate change. In this respect, some examples of transferable rights have already been developed in the WCPO, where they have been operating successfully between the PNA members for many years under the Vessel Day Scheme (Clark et al., 2021).

A significant additional challenge in a climate change scenario will be to consider transferability not only among

¹ A notable exception to this is the purse seine component of the WCPFC bigeye tuna fishery, which is subject to a fish aggregating device (FAD) closure period.

EEZs, or between EEZs and the high seas, but potentially between RFMOs. Such transfers will be aided by the establishment of compatibly defined catch or effort limits, which in turn flows on to how allocations are defined. For example, it will be much simpler to trade a catch or effort limit from the jurisdiction of one RFMO to another if both RFMOs define their limits and allocations in the same way. RFMOs must also consider to whom rights may be allocated. RFMOs allocate shares in limits to either flag States or coastal States. An ‘equitable’ allocation would be unlikely to be achieved if allocations were made to flag States on the basis of their fishing history in the EEZs of coastal States. In contrast, making allocations to coastal States based on past fishing in their EEZs would be consistent with international law (Davis et al., 2022) and would assist in mitigating the economic impacts of stock losses incurred by coastal States—and particularly by Pacific SIDS—as a result of climate change. Flag States would continue to have the opportunity to fish in coastal States’ EEZs by negotiating access for their vessels, consistent with the established practice.

As stocks shift and new scientific information emerges, the management frameworks for affected stocks will need to be flexible. The two RFMOs should therefore identify appropriate and adaptive management tools that can address new challenges, effectively manage new or emerging fisheries, and reduce pressure on shifting stocks. Harvest strategies, as described above, and compatibly defined catch or effort limits and transferable allocations, will provide a good basis for adaptive regulation of stocks, while maintaining biological sustainability of stocks and some degree of equity. Much of this will be breaking new ground for RFMOs.

These sorts of cooperative efforts would also anticipate advocacy efforts by private-sector market partners, who are increasingly recognizing the need to support jurisdictional or seascape approaches to seafood (Murphy et al., 2021a). The latter approaches seek to integrate market-incentives and ecosystem-based management at relevant ecological and political scales to drive fisheries sustainability and value creation across entire seafood production geographies (Kittinger et al., 2021; Murphy et al., 2021b). The UK-based super-market chain, TESCO, for instance recently announced a ‘seascape sourcing approach’ for tuna, and has developed a roadmap to transition to sourcing tuna from fisheries with an ecosystem-based management approach by 2030 (Holland, 2021; Tesco, 2021). Enhanced cooperation in the Pacific Ocean Basin, including through application of jurisdictional approaches spanning WCPFC and IATTC Convention Areas where appropriate, could therefore competitively position Pacific tuna as managed under a climate-resilient ecosystem approach, and further strengthen market partner interest in preferentially sourcing sustainable tuna from the region.

Compliance and enforcement

As noted above, the international legal framework for fisheries does not include any specific requirements about cooperation *between* RFMOs, including with respect to the compliance and enforcement of conservation and management measures. Nonetheless, as part of their obligation to cooperate through RFMOs, members of WCPFC and IATTC are responsible for ensuring the establishment of ‘appropriate cooperative mechanisms for effective monitoring, control, surveillance and enforcement’ of the stocks and areas under their jurisdiction (Article 10(h), UNFSA). In addition, as noted above, the constituent instruments of both RFMOs contain obligations to cooperate with other organisations—indeed, Article 22(4) of the WCPFC Convention specifically requires the Commission to consult with IATTC on measures relating to MCS for stocks that occur in the Convention Areas of both organisations. Neither the geographic nor substantive jurisdiction of each RFMO for compliance and enforcement will change with the climate-driven redistribution of tuna stocks, but the relative difficulty of effectively exercising this jurisdiction is likely to increase—particularly for IATTC, given the extent to which tropical tuna stocks are predicted to shift from the EEZs of the WCPO to the high seas of the EPO.

Fortunately, both organisations have already established many of the key MCS tools needed to ensure compliance and enforcement with their conservation and management measures—including a record of fishing vessels (IATTC, 2018b; WCPFC, 2018a); a regional observer programme (WCPFC, 2018b; IATTC, 2019a); a vessel monitoring system (VMS) (IATTC, 2014; WCPFC, 2014b); a procedure for establishing a list of vessels engaged in illegal, unreported and unregulated (IUU) fishing (IATTC, 2019b; WCPFC, 2019d); limitations on the transshipment of fish between vessels at sea (WCPFC, 2009b; IATTC, 2022a); and a set of minimum requirements for port State measures (WCPFC, 2017b; IATTC, 2021b)—and both organisations are in the process of developing standards for the electronic monitoring of fishing activity. Both IATTC and WCPFC have established procedures for sharing their IUU vessel lists with other RFMOs, and in the case of WCPFC, members are required to carry out inspections on any vessel entering their port that appears on the IUU list of another RFMO (WCPFC, 2017b). These measures should provide a reasonable basis to enforce whatever conservation and management measures are adopted to address the climate-driven redistribution of tropical tuna stocks.

However, the IATTC compliance and enforcement regime is not as developed as that of WCPFC in some ways. For example, while the WCPFC has established its own high seas boarding and inspection regime (WCPFC, 2006b), which has now been in operation for more than ten years, IATTC has not—although the

high seas boarding and inspection procedure established in Articles 21 and 22 of the UNFSA does apply between UNFSA parties in any area covered by an RFMO, including the IATTC Convention Area. In addition, although members of IATTC are required to ensure that all commercial fishing vessels longer than 24 meters carry and operate a satellite-based VMS, this is not a centralized system which reports directly to the Commission in the same way as the WCPFC VMS. This means that, unlike WCPFC member states, coastal State members of IATTC cannot get access to centralized VMS data for IATTC-registered vessels operating in their EEZs (as provided for in Article 24(8) of the WCPFC Convention), nor can they receive real-time VMS data for these vessels in areas of high seas adjacent to their EEZs for the conduct of compliance and enforcement operations (as established in paragraph 22 of Rules and Procedures for Access to High Seas Non-Public Domain Data) (WCPFC, 2009c). However, at its 2022 Commission meeting, IATTC did commit to improving its compliance review process (IATTC, 2022b).

With the strengths and weaknesses of the current arrangements in mind, there are some areas in which opportunities for enhancing cooperation and collaboration may be considered. The first, and most obvious, is in the overlap area. WCPFC and IATTC already have some basic measures in place for cooperation in compliance and enforcement in the overlap area—in particular, the MOC on Observers, which provides that approved observers from both observer programs who meet the necessary training requirements can be cross-endorsed to operate on vessels that fish on the high seas in both Convention Areas and the overlap area (WCPFC, 2011b). However, given the overlapping jurisdiction in this area, a sensible next step might be to consider the extent to which the existing arrangements are fit for purpose—both currently, and in anticipation of future changes in the distribution of fish stocks due to climate change. In particular, further scientific modelling might be needed to understand whether the overlap area is expected to be more productive or less productive, and whether and how the existing compliance and enforcement arrangements might need to be enhanced.

Second, although each RFMO will continue to oversee compliance and enforcement with respect to fishing for highly migratory stocks in the high seas of its own Convention Area, there are also opportunities for greater cooperation—and this might be particularly important in the high seas of the EPO, where the biomass of tropical tuna is expected to increase significantly. To date, the majority of tuna in the Pacific Ocean basin have been caught in the EEZs of WCPFC coastal State members, where compliance and enforcement can be carried out by coastal States in an

exercise of their sovereign rights. However, as Pacific tuna stocks shift progressively east and into the high seas of the EPO, where there are fewer oceanic islands to generate coastal State jurisdiction, this will become more difficult, because the primacy of flag State jurisdiction on the high seas will limit the jurisdiction of other States for compliance and enforcement activities. Further modelling of the likely climate-driven redistribution of each stock to these high seas areas will once again be important, this time in revealing the areas with the greatest potential increased risk of illegal fishing, and concomitant need for closer cooperation.

In terms of responding to such increased risk, consideration could be given to whether and how the joint working group model that is currently used to support negotiations between IATTC and the WCPFC-NC on management arrangements for Pacific bluefin tuna could be expanded, replicated or adapted to create a forum for addressing shared compliance and enforcement challenges. Since this model is based on a sub-set of members of WCPFC and IATTC (and even fewer major players), extending it to more complex tropical tuna fisheries involving many more countries and a more diverse mix of interests is likely to be challenging—but as the MOC on Observers has shown, such cooperation is possible.

Regardless of the forum in which such cooperation takes place, there are a number of areas in which work could be done to ensure that potential weaknesses in the compliance and enforcement system cannot be exploited. For example, consideration could be given to improving and expanding the operation and coverage of the WCPFC and IATTC VMS systems, so that vessels authorized to operate under the rules of either RFMO are required to transmit VMS data at all times when fishing in, transshipping catches in or transiting both Convention Areas—and in this case, the MOC on Data might need to be amended to ensure that relevant data and information are available to both RFMOs. In relation to electronic monitoring, the cooperative model established in the MOC for Observers, which allows vessels operating in the high seas of either Convention Area to use authorized observers from either RFMO to meet their observer coverage obligations, could be considered as a starting point. Finally, a review could be undertaken in cooperation with both RFMOs to see whether any best practice or innovative approaches developed and applied in one organisation might be able to be adapted and applied in the other, in order to enhance the overall high seas compliance and enforcement capacity of both organisations—such as the agreement in the WCPFC that coastal States can access near real-time VMS data for the high seas in areas up to 100 nautical miles adjacent to their EEZs, for the purpose of conducting MCS activities.

Discussion and actionable recommendations

As our analysis has shown, there are a wide range of important issues on which WCPFC and IATTC will need to cooperate to combat climate-driven changes to the distribution of tropical Pacific tuna stocks. Some of these need to be addressed as a priority, while some will be more appropriately addressed over a longer timeframe. Some are complex and will require potentially delicate and difficult discussions, while others are more straightforward and should be easily achievable. Drawing together the issues identified across the four areas of RFMO activity discussed above, three concrete actions with cross-cutting effects can be identified as priorities.

First, WCPFC and IATTC must establish a more comprehensive approach to cooperation, elevating it to a formal governance issue, in order to ensure that the two organisations can take and implement timely, informed, effective, and transparent decisions. At present, cooperation between the two RFMOs is based on a rather *ad hoc* combination of: observing meetings; exchanges between Executive Directors; sharing the text of conservation and management measures; exchanging data; authorizing reciprocal observer coverage; and cooperating on some northern stocks through the Joint Working Group. In adopting measures for the overlap area as a short-term solution in 2012, the two organisations agreed that a longer-term process should be established to explore avenues for managing tuna stocks in the entire Pacific Ocean (IATTC, 2012b; WCPFC, 2013). Ten years later, the time has come to establish a more formal mechanism to facilitate that sort of process, which will be critical to successful cooperation in the other issues identified in this paper. A low risk and immediately actionable starting point toward this would be to establish a joint working group, involving Secretariat staff and/or members of both Commissions, which could be charged to examine and provide recommendations on specific priority matters for cooperation—but over time, a more sophisticated mechanism is likely to be required.

A second priority for cooperation is to advance scientific knowledge of key issues to improve understanding of the biology and distribution of Pacific tuna stocks and how they will respond to climate change, and inform the conduct of stock assessments and the development of harvest strategies. International law requires States to make decisions based on the best scientific evidence available, to cooperate in scientific research, and to strengthen scientific research capacity in relation to highly migratory stocks—and it is evident from the discussion above that such research is essential to enable the two RFMOs to consider and prioritize action on other issues. Since there is already a significant practice of scientific collaboration to build

on, such as the Pacific-wide stock assessments for northern stocks which have been facilitated by the ISC, we suggest that agreement to cooperate on further issues—including sampling, modelling approaches and data collection—should be sought and actioned as quickly as possible.

Third, it is clear that WCPFC and IATTC must cooperate to define appropriate limits on fishing for each stock in a way that is compatible across the two organisations, taking into account their different members and management regimes. This is likely to be a complex task, which will necessarily be informed by some of the other areas of cooperation discussed in this paper—such as stock assessments, the development of harvest strategies, and a common understanding of how fishing limits are currently managed across the two RFMOs. It will also require an effective mechanism for cooperation, which ensures that the process is robust and transparent, and that the legitimate rights and interests of all States—as well as conservation and management principles—are properly taken into account. In this respect, one starting point might be for the two RFMOs to agree on some principles for dealing with shifting stocks to guide their work.

Finally, this discussion has also revealed some broader legal and policy issues which will require further consideration. First, as a matter of the international legal framework, further clarification is required as to how the ‘duty to cooperate’, which applies to each State whose nationals are fishing on the high seas, applies between RFMOs with jurisdiction over straddling and highly migratory stocks in adjacent areas of high seas. In this respect, the predicted climate-driven redistribution of Pacific tropical tuna stocks has highlighted a gap in the UNFSA, which does not clearly provide a framework for cooperation between RFMOs, or establish how ‘compatibility’ applies in relation to stocks which straddle areas of high seas under the competence of two different RFMOs, or the shift in distribution of fishery resources as a result of climate change. Second, not only are fish stocks predicted to move from an area under the jurisdiction of one RFMO to an area under the jurisdiction of another RFMO, but from areas under national jurisdiction to areas of high seas. This raises extremely difficult questions about the sovereign rights of coastal States, the potential to recognize or compensate loss and damage, and the allocation and transferability of rights from the EEZ to the high seas. Given the importance of tuna stocks to communities and economies in States across the Pacific Ocean—and particularly the predicted effects on many of the SIDS in the WCPO—finding just and equitable solutions to these difficult questions will require not only careful legal and policy analysis, but further cooperation between WCPFC and IATTC.

Author contributions

CG, RD, JB, QH and MT contributed to the conception and design of this paper. CG, RD and JB wrote the first draft of the

manuscript with contributions from all authors. All authors contributed to the article and approved the submitted version.

Funding

QH, BH and KS acknowledge support from the Nippon Foundation Ocean Nexus Centre at the University of Washington EarthLab. PO and JB acknowledge support from the Walmart Foundation (grant number 55149307). Pacific Community authors (GP, IS, PL and SN) were supported by the New Zealand Ministry for Foreign Affairs and Trade's 'Climate Change and Tuna Fisheries (ACT-0102118)' project. The findings, conclusions, and recommendations presented in this paper are those of the authors alone, and do not necessarily reflect the opinions of the funders.

References

- Aires-da-Silva, A., Maunder, M. N., Xu, H., Minte-Vera, C., Valero, J. L., and Lennert-Cody, C. E. (2020). *Risk analysis for management of the tropical tuna fishery in the Eastern Pacific Ocean*. IATTC document SAC-11-08 REV. Available at: https://www.iattc.org/GetAttachment/650968a3-f4c6-454a-8e8c-eef38fcb0dbb/SAC-11-08-REV-09-Jun-20_Risk-analysis-for-management.pdf.
- Aqorau, T. (2020). *Fishing for success: Lessons in Pacific regionalism* (Canberra, Australia: Australian National University). Available at: <https://dpa.bellschool.anu.edu.au/experts-publications/publications/7644/fishing-success-lessons-Pacific-regionalism>.
- Aqorau, T., Bell, J. D., and Kittinger, J. N. (20186408). Good governance for migratory species. *Science* 361, 1208–1209. doi: 10.1126/science.aav2051
- Azmi, K., and Hanich, Q. (2021). Mapping interests in the tuna fisheries of the Western and Central Pacific Ocean. *Ocean Coast. Manage.* 212, 105779. doi: 10.1016/j.ocecoaman.2021.105779
- Bahri, T., Vasconcellos, M., Welch, D., Johnson, J., Perry, R. I., Ma, X., et al. (Eds.) (2021). *Adaptive management of fisheries in response to climate change*. (Rome, Italy: Food and Agriculture Organization of the United Nations). Available at: <https://www.fao.org/3/cb3095en/CB3095EN.pdf>.
- Bell, J. D., Senina, I., Adams, T., Aumont, O., Calmettes, B., Clark, S., et al. (2021). Pathways to sustaining tuna-dependent Pacific Island economies during climate change. *Nat. Sustain.* 4, 900–910. doi: 10.1038/s41893-021-00745-z
- Butterworth, D. S. (2007). Why a management procedure approach? some positives and negatives. *ICES J. Mar. Sci.* 64 (4), 613–617. doi: 10.1093/icesjms/fsm003
- Castillo Jordán, C., Hampton, J., Ducharme-Barth, N., Xu, H., Vidal, T., Williams, P., et al. (2021). *Stock assessment of South Pacific albacore tuna*. WCPFC-SC17-2021/SA-WP-02. Available at: <https://meetings.wcpfc.int/node/12551>.
- Cavanagh, R. D., Broszeit, S., Pilling, G. M., Grant, S. M., Murphy, E. J., and Austen, M. C. (2016). Valuing biodiversity and ecosystem services: a useful way to manage and conserve marine resources? *Proc. R. Soc. B.* 283, 20161635. doi: 10.1098/rspb.2016.1635
- Clark, S., Bell, J., Adams, T., Allain, V., Aqorau, T., Hanich, Q., et al. (2021). "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" In *Adaptive management of fisheries in response to climate change*. 667. Eds. T. Bahri, M. Vasconcellos, D. Welch, J. Johnson, R. I. Perry, X. Ma and R. Sharma (Rome, Italy: Food and Agriculture Organization of the United Nations), 209–224.
- Davis, R. A., Hanich, Q., Haas, B., Cisneros-Montemayor, A. M., Azmi, K., Seto, K. L., et al. (2022). Who gets the catch? How conventional catch attribution frameworks undermine equity in transboundary fisheries. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.831868
- de Moor, C. L., Butterworth, D. S., and Johnston, S. (2022). Learning from three decades of management strategy evaluation in South Africa. *ICES J. Mar. Sci.* 79 (6), 1843–1852. doi: 10.1093/icesjms/fsac114
- Ducharme-Barth, N., Pilling, G., and Hampton, J. (2019). *Stock assessment of SW Pacific striped marlin in the WCPFC*. WCPFC-SC15-2019/SA-WP-07. Available at: <https://meetings.wcpfc.int/node/11232>.
- Engler, C. (2020). Transboundary fisheries, climate change, and the ecosystem approach: Taking stock of the international law and policy seascape. *Ecol. Soc.* 25 (4), 1–13. doi: 10.5751/ES-11988-250443
- FFA (2021). *Value of WCPFC-CA tuna catches 2021*. Pacific Islands Forum Fisheries Agency (Honiara, Solomon Islands: Forum Fisheries Agency). Available at: <https://www.ffa.int/node/425>.
- Frommel, A., Margulies, D., Wexler, J. B., Stein, M. S., Scholey, V. P., Williamson, J. E., et al. (2016). Ocean acidification has lethal and sub-lethal effects on larval development of yellowfin tuna, thunnus albacares. *J. Exp. Mar. Biol. Ecol.* 482, 18–24. doi: 10.1016/j.jembe.2016.04.008
- Hampton, J. (2017). *What is going on with bigeye tuna? SPC fisheries newsletter*. Available at: <https://coastfish.spc.int/en/component/content/article/479-spc-fisheries-newsletter-153.html>.
- Hampton, J., and Maunder, M. (2005). *Comparison of Pacific-wide, Western and Central Pacific, and Eastern Pacific assessments of bigeye tuna*. WCPFC-SC1-2005/SA-WP-2-Sup. Available at: <https://meetings.wcpfc.int/node/6444>.
- Hanich, Q., Jung, M., McDonald, A., Oh, S., Moon, S., An, J., et al. (2021). Tuna fisheries conservation and management in the Pacific Islands region: Implications for Korean distant water fisheries. *Asia-Pacific J. Ocean Law Policy* 6 (2), 192–220. doi: 10.1163/24519391-06020003
- Hare, S. R., Williams, P. G., Jordan, C. C., Hamer, P. A., Hampton, W. J., and Scott, R. D. (2021). *The Western and Central Pacific tuna fishery: 2020 overview and status of stocks*. WCPFC18-2021-IP02_rev1 tuna fisheries assessment report no. 21, Pacific community. Available at: <https://meetings.wcpfc.int/node/14499>.
- Holland, J. (2021). *Tesco introduces new tuna-sourcing approach*. seafood source, 2 march 2021. Available at: <https://www.seafoodsource.com/news/environment-sustainability/tesco-introduces-new-tuna-sourcing-approach>.
- IATTC (2005). *Cooperation with the Western and Central Pacific Fisheries Commission*. Document IATTC-73-11. Available at: <https://www.iattc.org/GetAttachment/9bd20b84-ded8-4c52-ace0-566d7c5cc091/IATTC-73-11%20-%20Cooperation%20with%20WCPFC>
- IATTC (2010). *Convention for the Strengthening of the Inter-American Tropical Tuna Commission Established by the 1949 Convention between the United States of America and the Republic of Costa Rica*. Available at: <https://www.iattc.org/getattachment/593fe044-9e3c-440b-8acf-e676d16b6618/Antigua%20Convention%20-%20text>.
- IATTC (2012a). *IATTC-WCPFC overlap area*. Document IATTC-83-Inf-B. Available at: <https://www.iattc.org/GetAttachment/113a3fd0-1349-4e68-97f1-fd0089799f4f/B.%20Overlap%20area>
- IATTC (2012b). *Recommendation C-12-11, IATTC-WCPFC overlap area*. Available at: <https://www.iattc.org/GetAttachment/e38aeaa0-029e-4534-9c65->

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

c2a5480f4efe/Recommendation%20on%20IATTC%20-%20WCPFC%20Overlap%20area.

IATTC (2014). *Resolution C-14-02, resolution (Amended) on the establishment of a vessel monitoring system (VMS)*. Available at: <https://www.iattc.org/GetAttachment/d7077963-3935-4a8a-b206-0c523f9dd57c/Vessel%20Monitoring%20System>.

IATTC (2018a). *Resolution C-18-03, amendment to Resolution C-13-03 supplementing Resolution C-05-02 on North Pacific albacore*. Available at: <https://www.iattc.org/GetAttachment/f17a945-791e-4cb4-8456-d744cd416b62/North%20Pacific%20albacore>.

IATTC (2018b). *Resolution C-18-06, resolution (Amended) on a regional vessel register*. Available at: <https://www.iattc.org/GetAttachment/cae37180-6ca8-4645-9dc7-3b633c9a14c6/Regional%20Vessel%20Register>.

IATTC (2019a). *Resolution C-19-08, resolution on scientific observers for longline vessels*. Available at: <https://www.iattc.org/GetAttachment/614c5692-74c5-40a7-a8b0-148ec052206/Observers%20on%20longliners>.

IATTC (2019b). *Resolution C-19-02, amendment to Resolution C-15-01 on establishing a list of vessels presumed to have carried out illegal, unreported and unregulated fishing activities in the Eastern Pacific Ocean*. Available at: https://www.iattc.org/GetAttachment/7478a141-ee4a-4594-b77c-a88326e693aa/C-19-02-Active_Amend-and-replaces-C-15-01-IUU-fishing.pdf

IATTC (2020). *Stock status indicators (SSIs) for tropical tunas in the Eastern Pacific Ocean*. IATTC document SAC-11-05. Available at: [https://www.iattc.org/getattachment/ae96afce-a437-496b-976f-01e801b69f7a/SAC-11-05-MTG_Stock-status-indicators-\(SSIs\)-for-tropical-tunas-in-the-EPO.pdf](https://www.iattc.org/getattachment/ae96afce-a437-496b-976f-01e801b69f7a/SAC-11-05-MTG_Stock-status-indicators-(SSIs)-for-tropical-tunas-in-the-EPO.pdf).

IATTC (2021a). *Resolution C-21-04, conservation measures for tropical tunas in the Eastern Pacific Ocean during 2022-2024*. Available at: https://iattc.org/GetAttachment/e3dc0a7e-e73c-4b8e-889e-a4cd2cdd7b8b/C-21-04-Active_Tuna-conservation-in-the-EPO-2022-2024.pdf.

IATTC (2021b). *Resolution C-21-07, resolution for an IATTC scheme for minimum standards for inspection in port*. Available at: <https://www.iattc.org/GetAttachment/f68ac134-db13-4463-b4d6-fe7d902c987b/Port%20State%20measures>.

IATTC (2022a). *Resolution C-22-03, Amendment to Resolution C-12-07 on establishing a program for transshipments by large-scale fishing vessels*. Available at: https://www.iattc.org/GetAttachment/241076b4-3ac9-4ead-91f9-1665a9e39ae9/C-22-03_Amendment-C-12-07-Transshipments.pdf.

IATTC (2022b). *Resolution C-22-02 on the process for improved compliance of resolutions adopted by the commission*. Available at: https://iattc.org/GetAttachment/8297974-0873-498a-8416-67ca268e023a/C-22-02_Compliance.pdf.

IATTC (2022c). *Resolution C-22-04 on a harvest strategy for North Pacific albacore in the Eastern Pacific Ocean*. Available at: https://iattc.org/GetAttachment/9d1676e8-b2af-4f40-88c1-5c3f0f8594ea/C-22-04_North-Albacore-Harvest-Strategy.pdf.

ISC (2019). *Stock assessment report for striped marlin (Kajikia audax) in the Western and Central North Pacific Ocean through 2017*. WCPFC-SC15-2019/SA-WP-09 WCPFC-SC15-2019/SA-WP-09. Available at: <https://meetings.wcpfc.int/node/11225>.

ISC (2022). *Stock assessment of Pacific bluefin tuna in the Pacific Ocean in 2022*. ISC/22/ANNEX/13/. Available at: https://isc.fra.go.jp/pdf/ISC22/ISC22_ANNEX13_Stock_Assessment_for_Pacific_Bluefin_Tuna.pdf.

ISSF (2022). *Status of the world fisheries for tuna: July 2022. ISSF technical report 2022-13*. Available at: <https://www.issf-foundation.org/issf-downloads/download-info/issf-2022-13-status-of-the-world-fisheries-for-tuna-july-2022/>.

Kittinger, J. N., Bernard, M., Finkbeiner, E., Murphy, E., Obregon, P., Klinger, et al. (2021). Applying a jurisdictional approach to support sustainable seafood. *Conserv. Sci. Pract.* 3, e386. doi: 10.1111/csp2.386

Lehodey, P., Hampton, J., Brill, R. W., Nicol, S., Senina, I., Calmettes, B., et al. (2011). "Vulnerability of oceanic fisheries in the tropical Pacific to climate change" in *Vulnerability of tropical Pacific fisheries and aquaculture to climate change*. Eds. J. Bell, J. E. Johnson and A. J. Hobday (Noumea, New Caledonia: Secretariat of the Pacific Community). 433–492.

Lehodey, P., Senina, I., Calmettes, B., Hampton, J., and Nicol, S. (2013). Modelling the impact of climate change on Pacific skipjack tuna population and fisheries. *Clim. Change* 119, 95–109. doi: 10.1007/s10584-12-0595-1

Lehodey, P., Senina, I., and Murtugudde, R. (2008). A spatial ecosystem and populations dynamics model (SEAPODYM) - modelling of tuna and tuna-like populations. *Prog. Oceanogr.* 78, 304–318. doi: 10.1016/j.pocean.2008.06.004

Lehodey, P., Senina, I., Nicol, S., and Hampton, J. (2015). Modelling the impact of climate change on South Pacific albacore tuna. *Deep Sea Res. Part II*, 113, 246–259. doi: 10.1016/j.dsr2.2014.10.028

Lehodey, P., Senina, I., Titaut, O., Calmettes, B., Conchon, A., Dragon, A., et al. (2014). *Project 62: SEAPODYM applications in WCPO*. WCPFC-SC10-EB-WP-02. Available at: <https://meetings.wcpfc.int/node/8722>.

Lodge, M. W., Anderson, D., Lorbach, T., Munro, G., Sainsbury, K., and Willock, A. (2007). *Recommended best practices for regional fisheries management organisations*. Available at: <https://repository.oceanbestpractices.org/bitstream/handle/11329/1456/39374297.pdf?sequence=1&isAllowed=y>.

Madigan, D. J., Boustany, A., and Collette, B. B. (2017). East not least for Pacific bluefin tuna. *Science* 357, 356–357. doi: 10.1126/science.aan3710

Maunder, M., Xu, H., Minte-Vera, C., Valero, J., Lennert-Cody, C., and Aires-da-Silva, A. (2022). *Skipjack tuna in the Eastern Pacific ocean: Interim assessment*. IATTC document SAC-13-07. Available at: <https://www.iattc.org/GetAttachment/Oacfc999-fbcd-4b07-9e8d-fc5f85fd88e8/SAC-13-07>.

McKechnie, S., Hampton, J., Abascal, F., Davies, N., and Harley, S. J. (2015). *Sensitivity of the WCPO bigeye tuna stock assessment results to the inclusion of EPO dynamics within a pacific-wide model*. WCPFC-SC11-2015/SA-WP-03. Available at: <https://meetings.wcpfc.int/node/9175>.

McKinney, R., Gibbon, J., Wozniak, E., and Galland, G. (2020). *Netting billions 2020: A global tuna valuation* (The Pew Charitable Trusts). Available at: <https://www.pewtrusts.org/-/media/assets/2020/10/nettingbillions2020.pdf>.

Mendenhall, E., Hendrix, C., Nyman, E., Roberts, P. M., Hoopes, J. R., Watson, J. R., et al. (2020). Climate change increases the risk of fisheries conflict. *Mar. Policy* 117, 103954. doi: 10.1016/j.marpol.2020.103954

Merino, G., Arrizabalaga, H., Arregui, I., Santiago, J., Murua, H., Urtizberea, A., et al. (2019). Adaptation of north Atlantic albacore fishery to climate change: Yet another potential benefit of harvest control rules. *Front. Mar. Sci.* 6, 620. doi: 10.3389/fmars.2019.00620

Moore, B. R., Bell, J. D., Evans, K., Farley, J., Grewe, P. M., Hampton, J., et al. (2020a). Defining the stock structures of key commercial tunas in the Pacific Ocean I: Current knowledge and main uncertainties. *Fish. Res.* 230, 105525. doi: 10.1016/j.fishres.2020.105525

Moore, B. R., Adams, T., Allain, V., Bell, J. D., Bigler, M., Bromhead, D., et al. (2020b). Defining the stock structures of key commercial tunas in the Pacific Ocean II: Sampling considerations and future directions. *Fish. Res.* 230, 105524. doi: 10.1016/j.fishres.2020.105524

Murphy, E. L., Bernard, M., Gerber, L. R., and Dooley, K. J. (2021a). Evaluating the role of market-based instruments in protecting marine ecosystem services in wild-caught fisheries. *Ecosystem Serv.* 51, 101356. doi: 10.1016/j.ecoser.2021.101356

Murphy, S. E., Farmer, G., Katz, L., Troëng, S., Henderson, S., Erdmann, M. V., et al. (2021b). Fifteen years of lessons from the seascape approach: a framework for improving ocean management at scale. *Conserv. Sci. Pract.* 3, e423. doi: 10.1111/csp2.423

NAFO (1999). *NAFO/GC doc. 99/8, resolution to guide the expectations of future new members with regard to fishing opportunities in the NAFO regulatory area*. Available at: <https://archive.nafo.int/open/gc/1999/gcdoc99-08.pdf>.

Nicol, S., Lehodey, P., Senina, I., Bromhead, D., Frommel, A. Y., Hampton, J., et al. (2022). Ocean futures for the world's largest yellowfin tuna population under the combined effects of ocean warming and acidification. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.816772

Østhagen, A., Spijkers, J., and Totland, O. A. (2020). Collapse of cooperation? the north-Atlantic mackerel dispute and lessons for international cooperation on transboundary fish stocks. *Maritime Stud.* 19, 155–165. doi: 10.1007/s40152-020-00172-4

Pentz, B., and Klenk, N. (2020). Understanding the limitations of current RFMO climate change adaptation strategies: the case of the IATTC and the Eastern Pacific Ocean. *Int. Environ. Agreements: Politics Law Economics* 20 (1), 21–39. doi: 10.1007/s10784-019-09452-9

Pentz, B., Klenk, N., Ogle, S., and Fisher, J. A. D. (2018). Can regional fisheries management organisations (RFMOs) manage resources effectively during climate change? *Mar. Policy* 92 (2018), 13–20. doi: 10.1016/j.marpol.2018.01.011

Pinsky, M. L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J., and Cheung, W. W. L. (2018). Preparing ocean governance for species on the move. *Science* 360 (6394), 1189–1191. doi: 10.1126/science.aat2360

PFRP (1999). "MHLC4 sets convention area, calls for scientific report," in *Pelagic Fisheries Research Program*, vol. 4 (2) April-June 1999. <http://www.soest.hawaii.edu/pfrp/newsletters/Apr-June1999.pdf>

Punt, A. E., Butterworth, D. S., de Moor, C. L., De Oliveira, J. A. A., and Haddon, M. (2016). Management strategy evaluation: best practices. *Fish and Fisheries* 17 (2), 303–334. doi: 10.1111/faf.12104

Rademeyer, R. A., Pleganyi, C. C., and Butterworth, D. S. (2007). Tips and tricks in designing management procedures. *ICES J. Mar. Sci.* 64 (4), 618–625. doi: 10.1093/icesjms/fsm050

Rayfuse, R. (2019). "Addressing climate change impacts in regional fisheries management organisations," in *Strengthening international fisheries law in an era of changing oceans*. Eds. R. Caddell and J. E. Molenaar (Oxford, United Kingdom: Hart Publishing), 247–268. doi: 10.5040/9781509923373.ch-011

- Scott, F., Scott, R., Yao, N., Pilling, G. M., and Hamer, P. (2022). *Mixed-fishery harvest strategy update*. WCPFC-SC18-2022/MI-WP-06. Available at: <https://meetings.wcpfc.int/node/16288>.
- Senina, I., Lehodey, P., Hampton, J., and Sibert, J. (2020a). Quantitative modeling of the spatial dynamics of South Pacific and Atlantic albacore tuna populations. *Deep Sea Res. Part II* 175, 104667. doi: 10.1016/j.dsr2.2019.104667
- Senina, I., Lehodey, P., Sibert, J., and Hampton, J. (2020b). Integrating tagging and fisheries data into a spatial population dynamics model to improve its predictive skills. *Can. J. Aquat. Fish. Sci.* 77, 576–593. doi: 10.1139/cjfas-2018-0470
- Senina, I., Sibert, J., and Lehodey, P. (2008). Parameter estimation for basin-scale ecosystem-linked population models of large pelagic predators: Application to skipjack tuna. *Prog. Oceanogr.* 78, 319–335. doi: 10.1016/j.pocean.2008.06.003
- Seto, K., Miller, N., Young, M., and Hanich, Q. (2021). Resource allocation in transboundary tuna fisheries: A global analysis. *Ambio*. 50, 242–259. doi: 10.1007/s13280-020-01371-3
- Spijkers, J., Singh, G. G., Wabnitz, C. C. C., Österblom, H., Cumming, G. S., and Morrison, T. H. (2021). Identifying predictors of international fisheries conflict. *Fish Fisheries* 22, 834–850. doi: 10.1111/faf.12554
- Tesco (2021). *Tesco takes action to improve marine sustainability, moving to a seascape approach for tuna sourcing*. Available at: <https://www.tescopl.com/news/2021/tesco-takes-action-to-improve-marine-sustainability-moving-to-a-seascape-approach-for-tuna-sourcing/>.
- Tremblay-Boyer, L., Carvalho, F., Neubauer, P., and Pilling, G. (2019). *Stock assessment for oceanic whitetip shark in the Western and Central Pacific Ocean*. WCPFC-SC15-2019/SA-WP06. Available at: <https://meetings.wcpfc.int/node/11231>.
- UN (1982). *United Nations Convention on the Law of the Sea*. Available at: https://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf.
- UN (1992a). *Rio Declaration on Environment and Development*. Available at: https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf.
- UN (1992b). *United Nations Framework Convention on Climate Change*. Available at: https://unfccc.int/sites/default/files/convention_text_with_annexes_english_for_posting.pdf.
- UN (1995). *Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks*. Available at: <https://documents-dds-ny.un.org/doc/UNDOC/GEN/N95/274/67/PDF/N9527467.pdf?OpenElement>.
- WCPFC (1999). *Report of the multilateral high-level conference on the conservation and management of highly migratory fish stocks in the Western and Central Pacific, fourth session* (Honolulu, Hawaii).
- WCPFC (2002). *Implementation of article 22, paragraph 4, of the convention: Cooperation with the Inter-American Tropical Tuna Commission (IATTC) to avoid duplication of measures*. WCPFC/PreCon/WP.12. Available at: <https://www.wcpfc.int/doc/wcpfcpreconwp12/cooperation-iattc>.
- WCPFC (2004). *Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean*. Available at: <https://www.wcpfc.int/doc/convention-conservation-and-management-highly-migratory-fish-stocks-western-and-central-pacific>.
- WCPFC (2006a). *Memorandum of understanding between the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean and the Inter-American Tropical Tuna Commission*. Available at: <https://www.wcpfc.int/doc/wcpfc-iattc-memorandum-understanding>.
- WCPFC (2006b). *CMM 2006-08, Western and Central Pacific Fisheries Commission boarding and inspection procedures*. Available at: <https://www.wcpfc.int/doc/cmm-2006-08/western-and-central-pacific-fisheries-commission-boarding-and-inspection-procedures>.
- WCPFC (2009a). *Memorandum of cooperation on the exchange and release of data between the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean and the Inter-American Tropical Tuna Commission*. Available at: <https://www.wcpfc.int/doc/wcpfc-iattc-memorandum-cooperation-exchange-and-release-data>.
- WCPFC (2009b). *CMM 2009-06, conservation and management measure on regulation of transshipment*. Available at: <https://www.wcpfc.int/doc/cmm-2009-06/conservation-and-management-measure-regulation-transshipment-0>.
- WCPFC (2009c). *Rules and procedures for the protection, access to, and dissemination of high seas non-public domain data and information compiled by the commission for the purpose of monitoring, control or surveillance (MCS) activities and the access to and dissemination of high seas VMS data for scientific purposes*. Available at: <https://www.wcpfc.int/doc/commission-09/rules-and-procedures-protection-access-and-dissemination-high-seas-non-public>.
- WCPFC (2009d). *CMM 2009-03, conservation and management for swordfish*. Available at: <https://www.wcpfc.int/doc/cmm-2009-03/conservation-and-management-swordfish>.
- WCPFC (2011a). *WCPFC-IATTC Overlap Area*. WCPFC8-2011/41 Rev 1. Available at: <https://meetings.wcpfc.int/node/7581>.
- WCPFC (2011b). *Memorandum of cooperation (MOC) on the cross-endorsement of WCPFC and IATTC observers when observing on the high seas of the convention areas of between the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean*. Available at: <https://www.wcpfc.int/doc/memorandum-cooperation-cross-endorsement-iattc-and-wcpfc>.
- WCPFC (2013). *WCPFC9 summary Report. 9th regular session of the Commission, Manila, Philippines, 2–6 December 2012*. Available at: <https://meetings.wcpfc.int/node/7867>.
- WCPFC (2014a). *CMM 2014-06, conservation and management measure on establishing a harvest strategy for key fisheries and stocks in the Western and Central Pacific Ocean*. Available at: <https://www.wcpfc.int/doc/cmm-2014-06/conservation-and-management-measures-develop-and-implement-harvest-strategy-approach>.
- WCPFC (2014b). *CMM 2014-02, conservation and management measure for commission VMS*. Available at: <https://www.wcpfc.int/doc/cmm-2014-02/conservation-and-management-measure-commission-vms>.
- WCPFC (2017a). *Discussion paper on membership process in WCPFC* WCPFC14-2017-DP18. Available at: <https://meetings.wcpfc.int/node/10480>.
- WCPFC (2017b). *CMM 2017-02, conservation and management measure on minimum standards for port state measures*. Available at: <https://www.wcpfc.int/doc/cmm-2017-02/conservation-and-management-measure-minimum-standards-port-state-measures>.
- WCPFC (2018a). *CMM 2018-06, conservation and management measure for WCPFC record of fishing vessels and authorisation to fish*. Available at: <https://www.wcpfc.int/doc/cmm-2018-06/conservation-and-management-measure-wcpfc-record-fishing-vessels-and-authorisation>.
- WCPFC (2018b). *CMM 2018-05, conservation and management measure for the regional observer programme*. Available at: <https://www.wcpfc.int/doc/cmm-2018-05/conservation-and-management-measure-regional-observer-programme>.
- WCPFC (2019a). *CMM 2019-03 on North Pacific albacore*. Available at: <https://www.wcpfc.int/doc/cmm-2019-03/conservation-and-management-measure-north-pacific-albacore>.
- WCPFC (2019b). *Resolution 2019-01, resolution on climate change as it relates to the Western and Central Pacific Fisheries Commission*. Available at: <https://www.wcpfc.int/doc/resolution-2019-01/resolution-climate-change-it-relates-western-and-central-pacific-fisheries>.
- WCPFC (2019c). *WCPFC16 summary report. 16th regular session of the Commission, Port Moresby, Papua New Guinea, 5–11 December 2019*. Available at: <https://meetings.wcpfc.int/node/11593>.
- WCPFC (2019d). *CMM 2019-07, conservation and management measure to establish a list of vessels presumed to have carried out illegal, unreported and unregulated fishing activities in the WCPO*. Available at: <https://www.wcpfc.int/doc/cmm-2019-07>.
- WCPFC (2021a). *CMM 2021-02, conservation and management measure for Pacific bluefin tuna*. Available at: <https://www.wcpfc.int/doc/cmm-2021-02/conservation-and-management-measure-pacific-bluefin-tuna>.
- WCPFC (2021b). *CMM 2021-01, conservation and management measure for bigeye, yellowfin and skipjack tuna in the Western and Central Pacific Ocean*. Available at: <https://www.wcpfc.int/doc/cmm-2021-01/conservation-and-management-measure-bigeye-yellowfin-and-skipjack-tuna-western-and>.
- WCPFC Scientific Committee (2019). *Southwest Pacific striped marlin (Kajikia audax) stock status and management advice*. Available at: <https://www.wcpfc.int/doc/09/southwest-pacific-striped-marlin>.
- Williams, P., and Ruaia, T. (2021). *Overview of tuna fisheries in the Western and Central Pacific Ocean, including economic conditions – 2020*. WCPFC-SC17-2021/GN-IP-01. Available at: <https://meetings.wcpfc.int/node/12527>.