Western and Central Pacific Fisheries Commission

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INCORPORATING CLIMATE CHANGE CONSIDERATIONS INTO CONSERVATION AND MANAGEMENT OF WCPO FISHERIES AND ECOSYSTEMS

WCPFC20-2023-12
10 November 2023

Prepared by the Secretariat

Purpose and Introduction

1. The purpose of this paper is to support the Commission's discussions at WCPFC20 on its decision[1] to incorporate climate change information and analyses in its work, as well as that of its subsidiary bodies.

2. This paper supplements the presentation provided by the Commission SSP on "Ecosystem and Climate Indicators" and seeks to inform deliberations on the role that the subsidiary bodies might play in implementing the Commission's decision.

3. This paper also reviews activities in other regional fishery bodies, considers "best practices" and gaps and challenges, and summarises discussions held by NC19, SC19, and TCC19 in 2023. Next steps for the Commission's consideration are included at the end of this paper.

4. Ocean warming due to climate change is causing irreversible changes to marine ecosystems and fisheries worldwide.[2] Potential impacts from climate change include shifts in species distribution and changes to productivity and species composition, all of which could undermine fisheries conservation and management efforts and disrupt established practices throughout the value chain.[3] Adverse effects on tropical tuna stocks in the Western and Central Pacific Ocean (WCPO) present a particular risk to Small Island Developing States (SIDS), many of which are already facing significant threats from sea-level rise and declines in coastal fisheries resources.[4]

5. The increasing evidence of climate impacts on ocean ecosystems calls for explicit consideration of climate stressors in fisheries management as well as climate-adaptive and ecosystem-based

[1] See paragraph 343 of WCPFC19 Summary Report.
[2] IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 21, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf.
[3] Bahri, T., Vasconcellos, M., Welch, D.J., Johnson, J., Perry, R.I., Ma, X. & Sharma, R., eds. 2021. Adaptive management of fisheries in response to climate change. FAO Fisheries and Aquaculture Technical Paper No. 667. Rome, FAO, pp. 1, 21. https://doi.org/10.4060/cb3095en.
[4] FFA members submission to WCPFC16-2019-DP04: https://meetings.wcpfc.int/node/11467

approaches.[5] Knowledge of anticipated climate impacts can inform development plans, enable timely responses by fisheries managers and contribute to increased resilience in fisheries by reducing their vulnerability to climate change.[6] Along with enhanced cooperation with other sectors and elevation of fisheries in national adaptation planning, addressing impacts like shifts in species distribution will require large-scale coordination across regional boundaries.[7]

International context

6. At its twenty-sixth session in 2021, the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) requested the Chair of the Subsidiary Body for Scientific and Technological Advice (SBSTA) hold an annual Ocean and Climate Change Dialogue in order to strengthen action on oceans and coasts under the UNFCCC.[8] This opens opportunities for fisheries scientists and managers to engage with and contribute to global efforts to develop mitigation and adaptation solutions.

7. Every six years, the Intergovernmental Panel on Climate Change (IPCC) produces an Assessment Report (AR), which assesses the best available science, including on the ocean and cryosphere, and incorporates these studies into scenarios for global temperature increases this century.[9] AR6, published in late 2021, focused on five future climate scenarios, two relatively optimistic ones, one middle-of-the-road, and two pessimistic scenarios.[10]

8. The Food and Agriculture Organization of the United Nations (FAO) promotes mainstreaming climate change into fisheries and aquaculture management, including explicit consideration of climate stressors in fisheries management.[11] Connections between adaptation plans and management and development actions are highly recommended, as are flexible approaches that allow for continuous adjustments as climate impacts are detected.[12] FAO also advises adopting climate-informed spatial management approaches and integrating equity and human rights considerations.[13]

History of WCPFC activities in response to climate change

9. The need for research on the issue of climate change and its associated ecosystem indicators has been raised since the early stages of the Scientific Committee. At SC4 in 2008, a Spatial Ecosystem and Population Dynamics Model (SEAPODYM) was introduced and updated annually. SEAPODYM provides a unique framework for the investigation of spatially and temporally resolved scientific

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[5] FAO. 2022. The State of World Fisheries and Aquaculture (SOFIA) 2022. Towards Blue Transformation. Rome, FAO, pp. 200-205. https://doi.org/10.4060/cc0461en.
[6] Ibid., pp. 202, 204.
[7] Ibid., p. 202; Bahri et al. 2021, p. 7.
[8] UNFCCC. Ocean and Climate Change Dialogue 2023 – Day 1. https://unfccc.int/event/ocean-and-climate-change-dialogue-2023-day-1 (accessed 11 November 2023).
[9] IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, p. 8. https://www.ipcc.ch/srocc/.
[10] Lee, J.-Y. et al., 2021: Future Global Climate: Scenario-Based Projections and Near-term Information. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V. et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 562. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter04.pdf.
[11] SOFIA 2022, supra, p. 201.
[12] Ibid., pp. 201-202.
[13] Ibid., pp. 204-205.

investigation into the plausible future abundance and distribution scenarios of tuna (specifically skipjack, yellowfin, and albacore tunas), and includes key population dynamics processes (i.e., spawning, movement, mortality)[14]. The model was considered a useful tool for assessing short to long term fine-scale spatial effects on tuna stocks as well as large-scale and climate effects. It was also considered an important tool for future stock assessment. One of the most likely future uses of SEAPODYM is as a tool to investigate the potential effects of greenhouse gas emissions (climate change) on tuna population abundance and distribution.

10. At SC10 (2014), a scientific peer review of SEAPODYM was requested to assist with guiding the WCPFC in evaluating potential model applications and its future work program. In 2015, SC11 had intensive discussion on the scope of work related to developing ecosystem indicators for possible incorporation into the management objectives. SC requested the Commission provide guidance on whether it would like the SC to move forward with the further development of ecosystem indicators for possible incorporation in the Commission's Management Options Workshop (MOW) process, building on the work of other international fisheries. However, no decision was taken by WCPFC12 that year.

11. In 2016, SC12 reviewed SSP paper SC12-EB-WP-02 (Ecosystem indicators: moving forward to design and testing) but no specific recommendations were provided. However, WCPFC13 adopted SC12's recommendation and endorsed the results of the review of SEAPODYM (SC12-EB-IP-14) as follows (Paragraph 659, SC12 Summary Report):

> *SEAPODYM has the potential to be a useful complementary model to MULTIFAN-CL for MSE work that includes spatial management. Similarly, the capacity of SEAPODYM to include alternate oceanographic states (e.g., ENSO phases and climate change projections) would allow climate proofing (reducing risks and capitalizing on opportunities presented by climate change) to be a consideration in the MSE work undertaken by WCPFC.*

12. At SC15 in 2019, climate change issues were first considered in the process of developing a harvest strategy framework. When SC15 reviewed information on the outputs for the skipjack harvest strategy and the work undertaken to test candidate MPs based upon the latest MSE framework (SC15-MI-WP-05), SC15 noted that work is progressing on identifying specific El Niño and La Niña distribution models so that non-stationary movement can be estimated and help account for possible climate change related impacts.

13. At WCPFC16 in 2019, the Commission held discussions on the implications of climate change for regional tuna stocks, including long term impacts of climate change that continue to suggest overall negative impacts on skipjack, yellowfin, and bigeye tuna in the WCPO. After extensive discussion, the Commission adopted the Resolution 2019-01 on *Climate Change as it Relates to the Western and Central Pacific Fisheries Commission*, which recognised the need for further work to understand the potential impacts of climate change and the relationship between climate change and fishing activities. Under Resolution 2019-01, the Commission resolved to:

    a. Consider the potential impacts of climate change on highly migratory fish stocks in the Convention Area and any related impacts on the economies of CCMs and food security

[14] SC16-EB-IP-06 *Review of SEAPODYM, including recent developments and as an ecosystem model for tropical tunas and important bycatch species in the Western Pacific Ocean*

and livelihoods of their people, in particular Small Islands Developing States and Participating Territories.

b. Support further development of science on the relationship between climate change and target stocks, non-target species, and species belonging to the same ecosystem or dependent on or associated with the target stocks, as well as interrelationships with other factors that affect these stocks and species and estimates of the associated uncertainties.

c. Take into account in its deliberations, including in the development of conservation and management measures, scientific information available from the Scientific Committee on the potential impacts of climate change on target stocks, non-target species, and species belonging to the same ecosystem or dependent on or associated with the target stocks.

d. Consider how climate change and fishing activities may be related and address any potential impacts in a manner consistent with the Convention.

e. Consider options to reduce the environmental impacts of the Commission related to headquarters operation and meetings of the Commission and its subsidiary bodies.

14. In 2022, SC18 recommended making “Ecosystem and Climate Indicators” a standing agenda item of the Ecosystem and Bycatch Mitigation Theme session at SC. This would provide a mechanism for the Scientific Committee to annually consider adopting candidate indicators presented to the Committee but also review and respond to existing trends/triggers identified in adopted indicators. SC18 also recommended the development and testing of “Ecosystem and Climate Indicators” as a project of the Scientific Committee. The establishment of a project is intended to ensure there is a mechanism for the Scientific Committee to easily track its progress towards evaluating and adopting candidate indicators. Another recommendation includes that available information and updates on the impacts of climate change be included or combined with status of stocks reporting.

15. The climate change discussions as they relate to a harvest strategy framework continued within SC, and WCPFC19 adopted SC18’s recommendation in 2022 to provisionally adopt the robustness set of operating models (OM) as listed in Table 1 of SC18-MI-WP-01. SC18 also discussed expanding this set of OMs to include additional uncertainties, including models that could account for effort-creep in the Japanese pole-and-line fisheries, likely changes on skipjack productivity due to the impacts of climate change, and a lower productivity (lower recruitment) ‘stress test’. This further work is an integral part of the MSE and was provided to SC19 (SC19-MI-IP-01). Accordingly, at SC19, the climate change scenarios (robust set), in particular the effects of warm pool expansion in the WCPO, were reflected in the *WCPO skipjack management procedure monitoring report* (Attachment 3, SC19 Outcomes Document). This requires further analysis of the SEAPODYM outputs and may occur over an extended timeframe.

16. At WCPFC19 in 2022, the Commission agreed that climate change will be a standing agenda item of the Commission and its subsidiary bodies (SC, NC, TCC) and to prioritize discussion of how best to incorporate climate change information and analyses into the Commission’s work. Accordingly in 2023, the NC19, SC19 and TCC19 included climate change considerations within the meeting agendas.

17. SC19 in 2023 reviewed South Pacific albacore operating models provided by SPC at SC19-MI-WP-04 (*Selecting and Conditioning Operating Models for South Pacific Albacore*), which focuses on outlining important sources of uncertainty that should be considered when conditioning operating models for south Pacific albacore management procedure. CCMs noted that several

other sources of uncertainty are needed to further develop the OM grid, including climate change scenarios. Several CCMs noted the importance of considering expanded areas of uncertainty as part of the robustness set and proposed, at this stage, that this should include scenarios of climate change and CPUE hyperstability, however further robustness tests may be required.

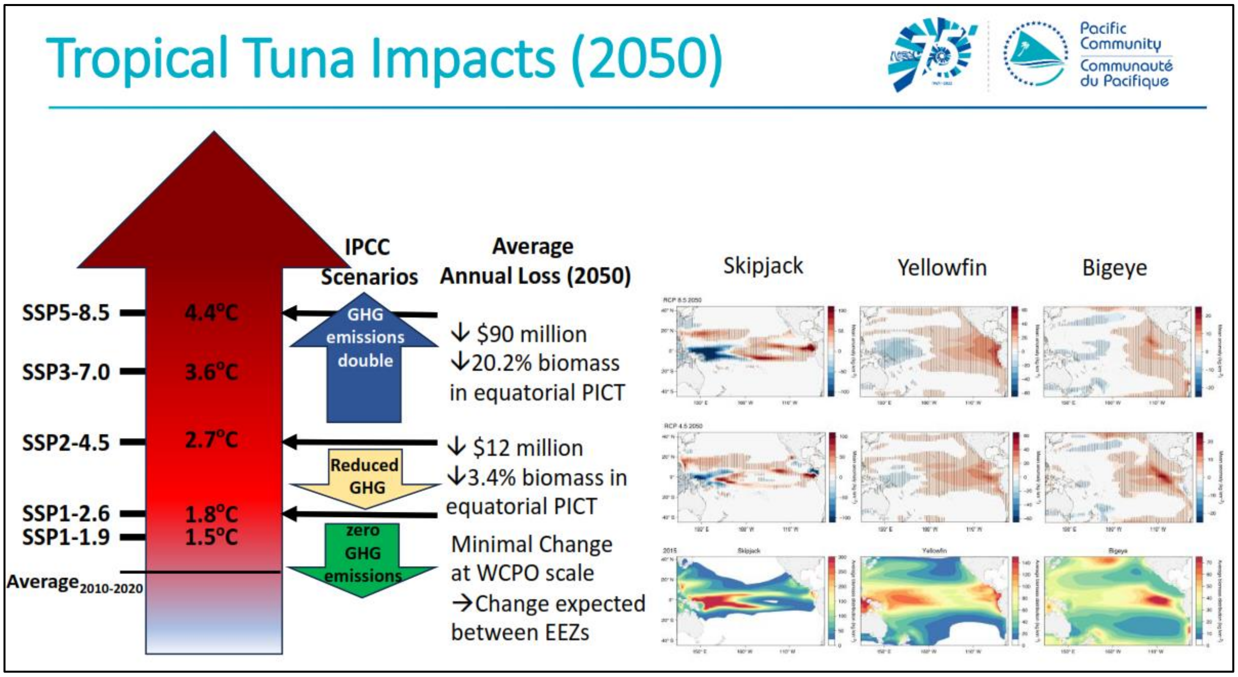


Figure 1. Five Intergovernmental Panel on Climate Change scenarios and the predicted potential effects, using the SEAPODYM model on the future biomass of tuna stocks in the WCPO. (Source: SPC. 2023)

18. Figure 1 illustrates the predicted potential impact on future tuna stock biomass from the five Intergovernmental Panel on Climate Change scenarios. The predicted potential impacts of tuna stock biomass were initial results provided through SPC's SEAPODYM analyses. SPCs work will be progressed and supported through the second phase of the Common Oceans Tuna Project (FAO).

Climate Change discussions in other regional fishery bodies (RFBs)

19. An international workshop on "Mainstreaming climate change into international fisheries governance – the case of Regional Fisheries Bodies in the Indo-Pacific region" - was organized by FAO with regional fishery bodies (RFBs) in October 2023.[15] The purpose of the workshop was to facilitate exchanges among RFBs from the Indo-Pacific region:

    a. on how they are integrating climate change in fisheries management advice;
    b. to discuss responses and opportunities to address the impacts of climate change on relevant fish stocks and ecosystems; and
    c. to propose actionable recommendations for future efforts.

[15] The workshop was held in Chennai, India from 16-20 October 2023. WCPFC Assistant Science Manager Ms. Elaine Garvilles attended the workshop.

20. Most RFBs are just starting their discussions and initiatives on climate change within their organizations. The Indian Ocean Tuna Commission (IOTC) and Inter-American Tropical Tuna Commission (IATTC) have recently adopted resolutions related to climate change, namely, Resolution 22/01 and Resolution C-2023-10, respectively.

21. At the global level, collaborative work is being supported to improve understanding of the potential impacts of climate change on tuna fisheries through the second phase of the Common Oceans Tuna Project, entitled "Sustainable Management of Tuna Fisheries and Biodiversity Conservation in the ABNJ (2022-2027)". This climate change impact related work is led by the Pacific Community (SPC) as a project executing partner, in partnership with Mercator Ocean International (MOI) and Conservation International. WCPFC is participating as a member of the Project Steering Committee and is providing in-kind co-financing to the project in the form of staff time and other operating expenses for activities devoted to supporting the project objectives.[16]

Good practices and lessons learned

22. The FAO workshop considered different "good practices and lessons learned" and concluded with the following:

    - Having a dedicated working group on climate change or adding climate change as a permanent agenda item.
    - Stock assessment workshops incorporating climate change aspects and networks.
    - Some existing CMMs that are regularly reviewed, giving a chance to assess and revise.
    - Policy/Strategy that addresses climate change.
    - MoUs that exist between RFBs to cooperate and share experience.
    - Projects with a focus on climate change.
    - Cooperation between RFBs and Regional Seas Organizations.

23. Specific to WCPFC Resolution 2019-01, this enabled WCPFC to implement actions to reduce the environmental impacts of the Commission's headquarters operations and meetings through:

    - The use of solar panels in Commission headquarters.
    - The use of biodegradable utensils (e.g. cups, plates, spoons, forks) in meetings/functions.
    - Participants being reminded to bring their own water bottles for use during the meetings to minimize the use of single-use plastic bottles.
    - Practicing recycling (e.g. aluminum cans, etc).

24. WCPFC also recognized that support from members is essential to progress any scientific work of the Commission related to climate change and mitigate its impacts on WCPO fisheries and ecosystem including target and non-target stocks. In addition, collaboration with other tuna RFMOs (tRFMO) and organisations allows sharing of information and learning from their experiences, including through participation in global meetings/workshops related to climate change, whenever possible.

[16] The inaugural project steering committee meeting for the Common Oceans Tuna Project was held at FAO Headquarters in Rome, Italy from 11 – 14 July 2023. The Project Steering Committee is responsible for providing general oversight of the execution of the Project and will ensure that all activities agreed upon under the Global Environment Facility (GEF) project document are adequately prepared and carried out. WCPFC Compliance Manager Dr. Lara Manarangi-Trott attended the project steering committee and was elected Chair to serve for a twelve-month term.

Gaps, challenges, and possibilities

25. This section draws on the discussions and outcomes from the FAO workshop as well as WCPFC meetings of the Science Committee, Northern Committee, and the Technical and Compliance Committee. This forms the basis for the Commission's discussion of potential taskings that seek to address the issues and identify ways to include climate change in the Commission's routine work programmes.

26. The inclusion of climate change as a topic for the Commission and its subsidiary bodies has presented opportunities to enhance WCPFC's work to:

    a) Integrate climate change analyses in the stock status and management advice that will aid in formulating CMMs, including guidelines on adaptive management and monitoring of highly migratory stocks (HMS) in response to climate change.

    b) Engage with other tRFMOs and organizations to share information and learnings, raise public awareness and foster sustainable solutions through international collaboration.

    c) Encourage cooperation and the support of member countries in progressing scientific work through the provision of necessary resources to conduct climate change analyses.

    d) Promote the development of a framework/strategies for incorporating climate change analyses and mitigating its impacts on target and non-target stocks into the WCPFC's processes.

    e) Establish dedicated working groups on climate change.

    f) Develop and/or update a list of species of concern for focused study and research related to climate change and harmonized methodological frameworks.

    g) Mainstream climate change as an integrated approach (similar to the ecosystem approach).

    h) Develop creativity in approaching management measures as measures need to be flexible and adaptable.

    i) Strengthen existing mechanisms of cooperation between RFMOs/RFABs including the sharing of data, information, and tools to support management (e.g. risk assessments, and vulnerability assessments).

27. It is acknowledged that most WCPFC members are currently experiencing the impacts of climate change in a number of ways and that a range of programmes exist in other regional and international organisations that are focused on addressing those impacts. The following Table lists general challenges and corresponding options to address these challenges that may help inform the Commission's discussions on appropriate future work:

Challenge	Options
Capacity building on the interpretation and communication of climate change analyses to various stakeholders needs to be addressed.	Develop and implement a communication strategy for climate change mitigation and adaptation for a range of stakeholders.
Limited resources (human, and financial), especially for developing states and participating territories that are highly vulnerable to climate change impacts (including	Develop funding strategies, initiate and develop contacts, and potential program

Challenge	Options
affecting their active participation in meetings/workshops.)	connections, and set up a funded structure for sustained implementation programs.
Research and data needs will necessitate additional resources which will include data collection, monitoring of fishing operations related to highly migratory stocks (HMS), and the development and application of climate change models.	Develop methodologies for improved integration of information and knowledge including collaboration and linkages with other tRFMOs and organizations.

28. In considering data, monitoring and science needs, the following list may assist:
    i. Need for fisheries-related time series
    ii. Need to regularly collect environmental/oceanographic data (e.g Oxygen, Nitrate, Chlorophyll/Primary productivity)
    iii. Climate change projections at a finer temporal and spatial scale
    iv. Information on migratory patterns and distribution shifts of fisheries resources
    v. Need to account for socio-economic elements in management responses through collection of social and economic data
    vi. Uncertainty in climate change (CC) projections and impacts on fisheries resources
29. The following list of scientific and management institutional needs may also be considered:
    i. Overlapping jurisdictions is a challenge regarding shifting stocks
    ii. Limited knowledge on risk-based approaches to management
    iii. Limited information-sharing on fisheries management, including the approach to enhance the resilience of fisheries and aquaculture in response to climate change

Update on 2023 activities in WCPFC

SC19 Outcomes[17]

30. SC19 reviewed SC19-EB-WP-01 (*Ecosystem and Climate Indicators*), which updated SC19 on progress regarding development of the candidate ecosystem and climate indicators for the WCPO. This paper addressed SC18's recommendation on the request of developing and testing of "Ecosystem and Climate Indicators" as a project of the Scientific Committee for the period 2024-2027. WCPFC CCMs supported SPC's proposed work plan in the paper for the development and testing of ecosystem and climate indicators for the period 2024-2027. SPC is planning to have an expert workshop in 2024 for technical analyses to develop and test candidate indicators and for the development of tools for communication to WCPFC and wider stakeholders.
31. SC19 noted that the SSP has completed a first screening of a subset of potential indicators for adoption and based on this experience recommended that the criteria identified at SC12 are

[17] See SC19 Outcomes Document, paragraphs 203-204.

appropriate for the initial screening of candidate indicators (Attachment 1)[18]. However, more specific criteria are needed for testing and adoption.

32. SC19 recommended adoption of the proposed workplan for the development and testing of ecosystem and climate indicators for the period 2024-2027 as contained in SC19-EB-WP-01 (*Ecosystem and Climate Indicators*).

NC19 Outcomes[19]

33. The NC19 discussed ways to incorporate climate change information and analyses in its work, particularly on considering impacts of climate change on northern stocks. The NC expressed general agreement to incorporate climate change analysis into NC discussions and to progress this work through engagement with other organizations to share information, learn from their experiences, raise awareness, and strengthen bonds through international collaboration. The NC Chair noted that tasking the ISC would not be sufficient, and more research and data collection efforts are necessary. He added that more financial and human resources should be provided to the ISC.

TCC19 Outcomes[20]

34. TCC received updates from the SSP on the status of WCPO tuna stocks and climate change impacts. Two aspects of climate change were described – the El Niño Southern Oscillation (ENSO) cycle and global warming. ENSO was noted to have had a major effect on tuna fisheries, and the knowledge it provided about the responses of tuna stocks and tuna fisheries to both warming and cooling events contributed to the predictions that were being made about their likely responses to continued global warming. The SSP explained several scenarios and their potential effects on biomass of tuna stocks. In summary it was noted that climate change can impact a stable fishery and make stocks unhealthy even without change in fishing effort, work is still to be done on establishing harvest strategies to maintain stocks at desired levels and improving the health of some non-target species.

35. In the discussions, TCC recognized that there is increased importance for the Commission to ensure information and data collection to better understand the impacts of climate change and implications for management of WCPFC fisheries. The Secretariat and some participants suggested that TCC could have a role in ensuring that the Commission can acquire the data to enable scientists in their work in understanding climate change impacts and to support managers who are charged with ensuring the conservation and sustainable use of WCPO fisheries and ecosystems. The TCC Chair noted that TCC is expected to have an ongoing role in monitoring activities, including in adaptive management, in the implementation of monitoring strategies under the harvest strategy approach and in supporting the SC work to test climate change indicators.

36. TCC19 recommended that the TCC Chair and Secretariat consider how ongoing work on developing monitoring strategies for management procedures and SC19's recommendation to develop and test ecosystem and climate indicators would intersect with the work of TCC, including how these may be included in the TCC workplan. TCC19 also noted it would be beneficial to

[18] The rationale and potential design and testing criteria for ecosystem indicators are in Annex 1 and the subset of potential indicators are in Annex 2 of SC19-EB-WP-01. Annex 2 of the working paper was also tabled at TCC19 as WCPFC-TCC19-2023-IP12.

[19] See NC19 Summary Report, paragraphs 40-45.

[20] See Draft TCC19 Summary Report, paragraphs 181-204.

receive direction from the Commission on incorporating climate change discussions into its agenda.

Recommendations

37. The Commission is invited to:

    a. note with appreciation the Ecosystem and Climate Indicator Report Card (Attachment 1) prepared by the SSP to improve understanding of the potential impacts of climate change on tuna fisheries globally, and the support to this work from the second phase of the Common Oceans Tuna Project.

    b. request that the Ecosystem and Climate Indicator Report Card be updated and presented annually to the Commission and its subsidiary bodies in support of furthering the consideration of climate change impacts in WCPFC's work.

    c. recognise that there is increased importance for the Commission to ensure information and data collection is adequate to support improved and updated understanding by the Commission on the impacts of climate change and implications for management of WCPFC fisheries.

    d. task SC and TCC to include as part of the standing agenda item on climate change a review of available data to inform the Commission on climate change impacts to stocks and ecosystems in the WCPO, and the potential effects of climate change on related fishing activities. The annual review of available data should also provide advice and recommendations to the Commission which identifies information gaps, necessary analyses, and any additional tasks that may further enhance the Commission's ability to account for climate change impacts on WCPFC fisheries.

    e. task the Secretariat with continuing to provide a brief that summarises updates on international and RFB developments.

Annex 2 Ecosystem and Climate Indicator Report Card

Details on the calculations for each indicator in Report Cards 1 to 3 are provided below. Code, data, and associated figures and results for each indicator are available in the GitHub repository for the paper: github.com/PacificCommunity/OFP-FEMA-ecosystem-indicators.

Report Card 1. Environment Indicators

All environmental indicators were calculated from outputs of the Bluelink Ocean ReANalaysis 2020 (Chamberlain et al. 2021), a three-dimensional, physical ocean model with a spatial resolution of 1/12°. Monthly outputs were used to allow averaging over seasons, when required by an indicator. The code used to generate indicators from pre-processed netcdf output files from BRAN2020 can be found at the GitHub repository for this paper (see link above).

A.1 *Sea Surface Temperature Anomalies*

Sea surface temperature (SST) anomaly was calculated across three spatial extents. In all three cases, the annual value was the mean anomaly of all cells within the spatial extent, from a baseline mean across the period 1993-2021. For the WCPO SST anomaly, this spatial extent was bounded by a square with corners at 50°N, 130°E and 50°S, 150°W (see Figure 1 in SPC-OFP 2021). The WCPO equatorial SST anomaly included only cells bounded by the box with corners at 5°N, 130°E and 5°S, 150°W. In the case of the warm pool extent SST anomaly, the spatial extent of cell anomalies changed each year. Following a typical characterisation of the warm-pool extent, only those cells that exceed a mean sea surface temperature of 29°C during the period November to April were included in anomaly calculations for each year (e.g. Roxy et al. 2019; Hu and Federov 2017). The mean anomaly of cells included in this extent, from their respective 1993-2021 baseline, was then calculated annually for the period November to April.

A.2 *Warm Pool Indices*

Each year, the extent of the warm pool was calculated using the method described above. In the case of the mean warm pool size, the number of cells with a mean sea surface temperature greater than 29°C during November to April was used to provide the approximate area encompassed by the warm pool each year. The eastern boundary of the warm pool was calculated following a similar methodology to Qu and Yu (2014) and others, where strong changes in sea surface salinity (SSS) across the equator were used to indicate the presence of a barrier layer between increased fresh water in the warm pool meeting colder, high salinity water from the east. Mean SSS between 2°S and 2°N was calculated during the November to April period, and the centre of the largest longitudinal change across a 10° window identified as the eastern limit of the warm pool. The mean warm pool mixed layer depth (the depth at which water mixing results in uniform buoyancy of a particular value) was simply taken directly from BRAN2020, and averaged over the extent of the warm pool during the period November to April each year.

A.3 *Climate Indices*

Here, we have presented two climate indices which relate to changes in the WCPO ecosystem. The Oceanic Niño Index (ONI) tracks three-month averaged SST anomalies across regions of the equatorial Pacific from a moving 30-year average temperature, and one method of identifying likely El Niño or La Niña events. The Interdecadal Pacific Oscillation index (IPO) measures longer-term climate cycles affecting the extent of the Pacific basin, and switches phases roughly each 15-30 years. Positive phases are associated with increased warming in the tropics and cooler northern Pacific climate, and negative phases are associated with cooler temperatures in the tropics and increased temperatures in the higher latitudes.

Report Card 2. Annual Tuna Catch & Fishing Effort indicators

A.4 ***Annual Tuna Catch***

These indicators describe trends in annual catch estimates (in metric tonnes) of the four main tuna species (skipjack, yellowfin, bigeye and albacore) targeted within the WCPFC Convention Area (WCPFC-CA), between 1990 and 2022, inclusive. Data for the calculations were extracted from SPC's 'a_model' database, a collation of S_BEST, L_BEST, and P_BEST catch data aggregated at 5° x 5° resolution for all fishing gears, and S_BEST and L_BEST containing aggregated, raised catch data from the purse-seine fishery at 1° x 1°, and the longline fishery at 5° x 5°, respectively. See Hare et al. (2023) [SC19/SA-WP-06] for a compilation of all fishery indicators for these target tunas.

A.5 ***Fishing Effort***

Data to characterize trends in fishing effort were extracted from SPC's S_BEST and L_BEST databases from 1990-2033, inclusive, for purse seine (PS) and longline (LL) catch and effort data, respectively. These databases contain aggregated, raised fishing effort across the WCPFC-CA. We focused on purse seine and longline data as they represent the major gear sectors for the region. For the purse seine fishery, the individual fishing set was considered the metric of effort, while for longline, effort was defined as the number of hooks fished.

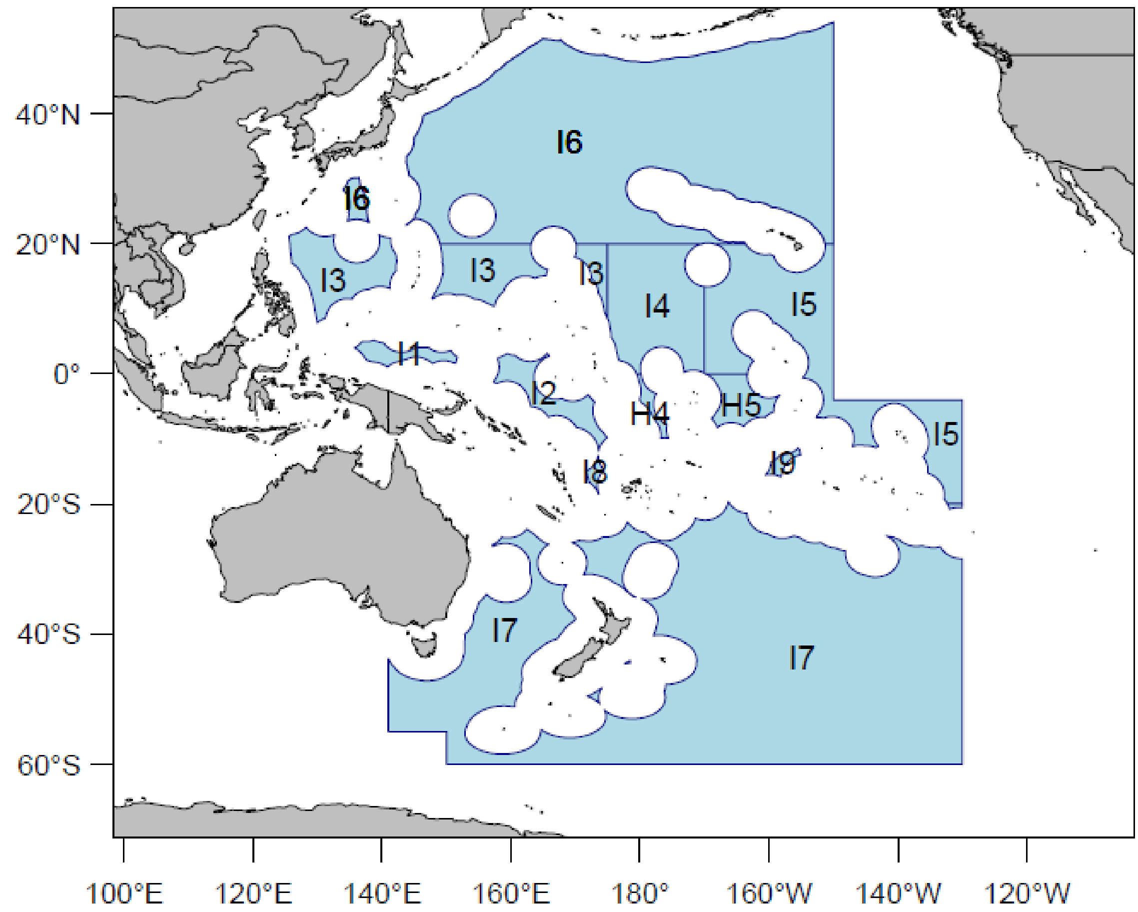
The central tendency of purse seine fishing effort was defined here by the 'centre of gravity', i.e. the mean location (latitude and longitude) of fishing effort. This was calculated by year for each fishing mode i.e. 'unassociated' free-school sets (UNA) versus 'associated' sets (ASS). We present only the annual longitudinal centre of gravity for purse seine, as the fishery remains relatively stable latitudinally year on year. It should be noted that for this analysis, associated sets refers to sets made on drifting FADs and drifting logs or debris; this does not include sets made around whales or whale sharks, nor does it include anchored FAD sets.

The central tendency indicators were not calculated for the longline fishery because of the diversity in targeted species and the areas associated with different targeting behaviours. At this time, a measure of central tendency for the longline fishery was not expected to be an informative indicator of ecosystem dynamics.

In addition to the central tendency of fishing effort, area occupied by the purse seine and longline fisheries was calculated. Area occupied is a measure of the distribution of effort across the spatial domain of the WCPFC and was calculated as the sum of the area (in km^2) of unique 1° x 1° cells fished by the purse seine fishery and 5° x 5° cells fished by the longline fishery, in each year evaluated.

With growing interest in tracking changes in the distribution of purse seine effort inside and outside EEZs within the WCPFC-CA, we include a new effort indicator this year, representing the proportion of purse seine sets made in High Seas areas, disaggregated by fishing mode. High Seas areas included in the calculations comprise the I1, I2, I3, I4, I5, I6, I7, I8, I9, H4, H5 regions (Figure A1).

Figure A1. WCPFC-CA High Seas regions and boundaries.



Report Card 3. Biology & Bycatch Indicators

A.6 *Tuna Condition*

The mean fork length (cm) of skipjack tuna was calculated annually from all length measurements recorded for longline, purse seine and pole-and-line catches made in the WCPFC-CA between 1990 and 2022, inclusive. Length data were drawn from observer and port sampling records, in this case contained in SPC's 'BioDaSys', 'OBSV_MASTER' and 'Tufman2' databases. Following the methods used for the fishing effort indicators (see section A.5) we focussed our attention on the purse seine and longline data as they represent the major fisheries in terms of catch, and were available across the full 33-year time series. Where required, published 'conversion factors' were used to convert length measurements to fork length (UF) in cm. These conversion factor equations are updated as new data comes to hand, and are housed in an online database managed by SPC. We refer readers to Macdonald et al. 2023 [SC19/ST-IP-04] for an update on progress on this conversion factor work.

The mean fork length (cm) of yellowfin and bigeye tuna caught in the longline fishery was calculated annually from all length measurements recorded for each species within the WCPFC-CA between 1990 and 2022, inclusive. The length data were again drawn from observer and port sampling records contained in SPC's 'BioDaSys', 'OBSV_MASTER', 'FISH_MASTER' and 'Tufman2' databases. We focussed on the longline data for yellowfin and bigeye, as this gear typically selects for larger individuals than purse seine, placing a lower bound on the length range considered. This allowed us to maximise precision, while minimising potential gear-related bias in tracking shifts in mean length through time. As for skipjack, length measurements were converted to fork length (UF) in cm where required using published conversion factors for each species.

Mean fish condition, defined by the average relative condition factor $K_{rel} = WW/aUF^b$ (where WW is an individual's whole weight (kg) and aUF^b is the model predicted whole weight at fork length UF (cm)) was calculated annually for skipjack, yellowfin and bigeye tuna separately, based on length and weight data from longline catches made across the WCPFC-CA between 1990 and 2022, inclusive. The data were drawn from observer and port sampling records contained in SPC's 'BioDaSys', 'OBSV_MASTER', 'FISH_MASTER' and 'Tufman2' databases.

Published conversion factors were again used to convert length measurements to fork length (UF) in cm, and weight measurements to whole weight (WW) in kg.

For each species, we elected to model predicted weight from the longline records only. This decision was based around two points. i) Data coverage: the broad spatial and temporal extent of coupled length and weight measurements available from the longline fishery provide the most reliable estimates for calculating K_{rel}. ii) Mismatch in scales: given the different size selectivities, areas fished and length of time series available for longline, purse seine and pole-and-line gears, there is potential for the shape of the length-weight curve to differ among gears/areas/time periods fished. Therefore, by fitting our models to the longline data only we aimed to reduce these possible biases in monitoring changes in fish condition across the 1990 to 2022 time series. We note that new sampling initiatives are being developed to enhance data collection on purse seine vessels, and as further data becomes available, gear-to-gear comparisons could be reported in future iterations of these Report Cards.

Fat content represents the percentage of lipids in the tuna flesh, and we consider this a potentially useful second indicator of tuna condition that complements the measurement of K_{rel}. The percentage of fat is measured using the Distell's fish 'fatmeter' model 692 by a simple contact of the instrument's sensor on the skin of the fish. Collection of fat content data on tropical tunas is now part of routine biological sampling tasks during PTTP tuna tagging cruises, and the dataset is growing steadily. Fat content is dependent on fish size; hence to avoid introducing bias, only skipjack, yellowfin and bigeye tuna measuring 40-60cm fork length were used to calculate annual mean fat content by species.

A.7 *Bycatch Species*

The observer and aggregate effort datasets used to estimate the amount of catch for the bycatch species were extracted from SPC data holdings. The overall approach was to estimate stratified catch rates using a combination of presence/absence models and bootstrap sampling for catch when present, and then to use these catch rates to estimate bycatch for unobserved sets. Recorded catches were used directly for observed sets, and assumed to be known without error.

For purse seine, the methods are fully described in Peatman and Nicol (2021), and a summary of the approach is provided here. The estimates cover the large-scale equatorial purse seine fishery operating in the WCPFC-CA. Bycatch estimates were not generated for purse seine fleets for which SPC holds limited representative observer data, namely small-scale domestic fisheries of Indonesia, Vietnam and the Philippines, and purse seiners operating in temperate waters. Bycatch estimates were generated in units of individuals for billfish, sharks and rays, with finfish bycatch estimated in units of metric tonnes. These units match those most commonly used by observers when recording catch volumes of the respective species groups and were considered to provide the most accurate dataset of observed catches in SPC's purse seine observer data holdings.

Presence/absence models were fitted to observer data using Generalised Estimating Equations (GEEs) with year, sea-surface temperature (SST – Reynolds et al. 2002), and categorical variables for quarter and school association as explanatory variables. The fitted presence/absence models were used to estimate the probability of presence for a given estimation group and strata (combinations of year, quarter and school association). The volume of catch when present was estimated by bootstrap sampling from sets with observed captures, stratified by association type. Estimates of the overall bycatch rate were then obtained for each estimation group and strata by taking the product of the probability of presence and the volume of catch when present. As such, the units of bycatch rate were numbers or metric tonnes per set. The estimated catch rates were then applied to the number of unobserved sets in each strata, to calculate unobserved bycatch. The estimates of unobserved bycatch were then combined with recorded bycatch from observed sets to give estimates of total bycatch.

For longline, the methods are fully described in Peatman and Nicol (2020), and a summary of the approach is provided here. The estimates cover longline fishing from 2003 to 2018 in the WCPFC-CA, including the region overlapping the IATTC Convention Area. Catch estimates do not include catches from the domestic longline fisheries of the Philippines, Vietnam and Indonesia, referred to in this report as 'west-tropical domestic fisheries', as SPC holds little representative observer data for these fisheries. Catch estimates also do not include former shark-targeted longline fisheries in the Papua New Guinea (PNG) and Solomon Islands (SB) EEZs as these fisheries are not included in aggregate longline catch and effort data held by SPC.

Hooks between float (HBF) specific aggregate catch and effort data, i.e. 'L_BEST_HBF' data, were used to estimate the proportions of aggregate effort data by HBF categories. K-means clustering was applied to aggregate longline catch data to partition longline effort into groups with similar species compositions.

GEEs were again used to model catch rates with year, sea-surface temperature (SST), HBF, and categorical variables for flag, and the species composition cluster for the 'L_BEST' strata as explanatory variables. A simulation modelling framework was used to estimate catches. First, the effort dataset for catch estimation was generated by aggregating HBF-specific effort surfaces to a resolution of year, SST, HBF, catch composition cluster, flag and region. Then estimated catches were obtained by taking the product of the catch rates and the effort.

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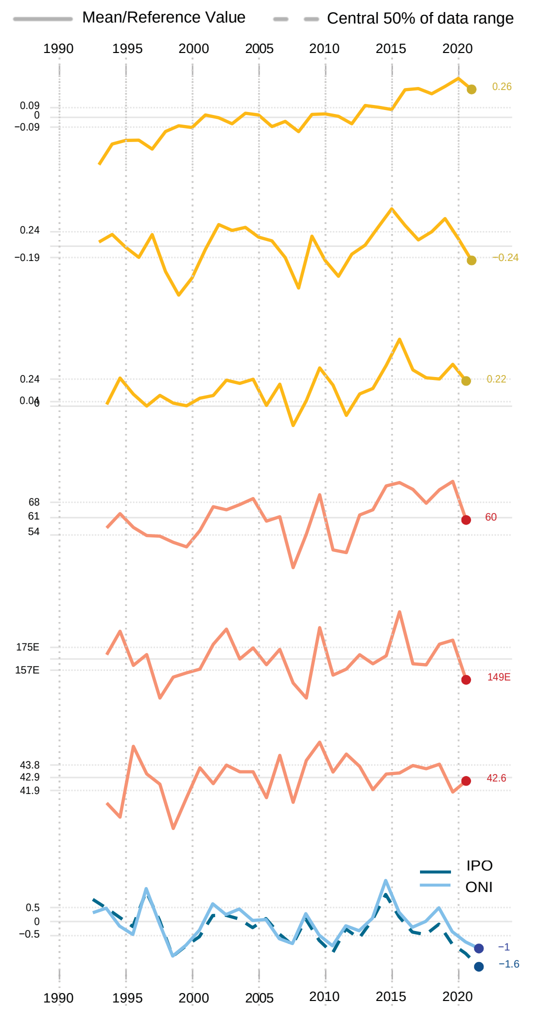
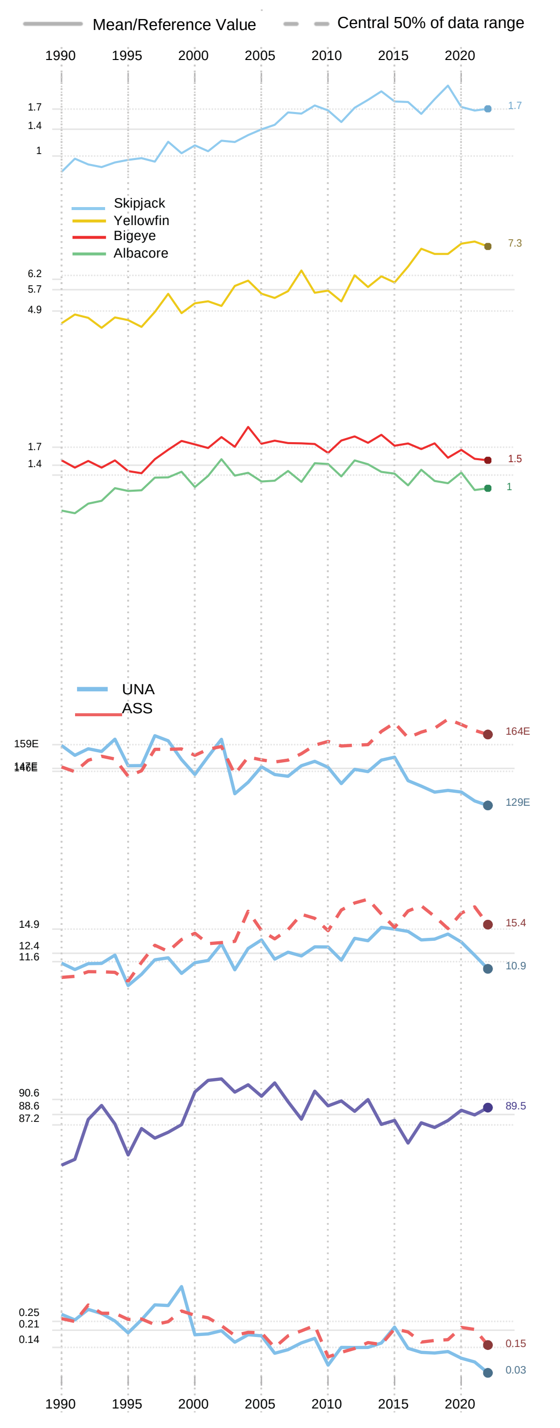
Indicator	Description	Notes	Time-series
Sea Surface Temperature Anomalies (ANNEX 1 - A.1)			
Annual SST Anomaly	Mean annual SST anomaly (°C) across **WCPO area**	• Derived from ocean models • WCPO area western limit of 130°E • Anomaly from mean temperature 1993-2021	
	Mean annual SST anomaly (°C) across **WCPO equatorial zone**	• Derived from ocean models • Equatorial zone 5°S-5°N • Anomaly from mean temperature 1993-2021	
Nov-Apr Warm-pool SST Anomaly	Mean annual SST anomaly (°C) within warm-pool extent	• Derived from ocean models • Warm-pool defined by mean Nov-Apr temperature > 29°C	
Warm-pool Indices (ANNEX 1 - A.2)			
Mean Size of Warm-pool	Approximate size of warm-pool in millions of km^2	• Derived from ocean models • Warm-pool defined by mean Nov-Apr temperature > 29°C	
Eastern Limit of Warm-pool Boundary	Longitude of strongest sea surface salinity boundary	• Derived from ocean models • Boundary defined as largest change over 10° distance	
Mean Warm-pool Mixed Layer Depth	Mean depth (m) of the mixed layer within warm-pool	• Derived from ocean models • Layer over which water temperature is homogenous	
Climate Indices (ANNEX 1 - A.3)			
Oceanic Niño (ONI) and Interdecadal Pacific Oscillation (IPO) Index	ONI indicates SST anomalies in the Niño 3.4 region during Nov-Jan each year IPO represents long-term oscillation between El Niño favourable and La Niña favourable phases	• ONI values > 0.5 indicative of El Niño events, values < -0.5 indicative of La Niña • IPO values > 0 indicative of more El Niño events, < 0 indicative of more La Niña events • Time series from 1993-2021	



Report Card 2. Annual Tuna Catch & Fishing Effort Indicators

Indicator	Description	Notes
Annual Tuna Catch (ANNEX 1 - A.4)		
Annual Tuna Catch	Total **Skipjack** catch for entire WCPFC-CA, in millions of tonnes	• Data from all fishing gears combined • See Hare et al. (2023) [SC19/SA-WP-06] for a compilation of all fishery indicators for skipjack
	Total **Yellowfin** catch for entire WCPFC-CA, in 100,000 of tonnes	• Data from all fishing gears combined • See Hare et al. (2023) [SC19/SA-WP-06] for a compilation of all fishery indicators for yellowfin
	Total **Bigeye** and **Albacore** catch for entire WCPFC-CA, in 100,000 of tonnes	• Data from all fishing gears combined • Data for albacore pertains to the South Pacific stock only • See Hare et al. (2023) [SC19/SA-WP-06] for a compilation of all fishery indicators for bigeye and South Pacific albacore
Fishing Effort (ANNEX 1 - A.5)		
Annual, Longitudinal Centre of Purse Seine Effort	Mean longitudinal centre of gravity of purse seine effort	• Purse seine effort is disaggregated into unassociated (UNA) and associated (ASS) sets • Associated sets include those made on drifting FADs as well as drifting logs and debris
Annual Area of Fishing Effort	Total area occupied by **Purse Seine** fleet annually, in millions of km^2	• The sum of the area of 1° x 1° cells with at least one purse seine set, aggregated annually • Purse seine effort is disaggregated into unassociated and associated sets
	Total area occupied by **Longline** fleet annually, in millions of km^2	• The summed area of 5° x 5° cells with at least one longline set, aggregated annually
Effort in High Seas Areas	Annual proportion of **Purse Seine** sets made in High Seas areas within the WCPFC-CA	• High Seas areas comprise the I1,I2,I3,I4,I5,I6,I7,I8,I9,H4,H5 regions • Proportions calculated relative to the total numbers of sets made, for unassociated and associated sets separately

Time-series



Report Card 3. Biology & Bycatch Indicators

Indicator	Description	Notes	Time-series
Tuna Condition (ANNEX 1 - A.6)			
Mean Length of Tuna species	Mean fork length (cm) of **Skipjack** tuna caught by WCPO purse seine and longline fisheries	• Length data sourced from purse seine and longline • Length measurements recorded at sea and in port	
	Mean fork length (cm) of **Yellowfin** and **Bigeye** tuna caught by WCPO longline fisheries	• Length data sourced from longline only • Length measurements recorded at sea and in port	
Mean Condition Factor from Longline Catch	Mean observed individual tuna weight divided by predicted weight at length	• A measure of relative tuna 'fatness' • Predicted weight modelled from longline records spanning 1990 to 2022, for each species separately	
Mean Fat Content of Sampled Tuna	Mean fat content (%) of **Skipjack**, **Yellowfin** and **Bigeye** tuna measured by fatmeter during annual PTTP research cruises informing on tuna condition - fatter fish being considered in better condition	• Second measure of tuna 'fatness' • Calculated for tuna between 40 to 60 cm fork length. • Years available: 2007-2009, 2011-2013, 2019-2021 • Sample size varies considerably by year and species, with more data in later years	
Bycatch Species (ANNEX 1 - A.7)			
Annual Finfish Bycatch	Estimated **Unassociated Purse Seine** catch of finfish bycatch in 1000s of metric tonnes	• Excluding billfish and tuna • Catch estimates based on observer data, excluding small-scale domestic fisheries of Indonesia, Vietnam, the Philippines, and temperate water purse seiners	
	Estimated **Associated Purse Seine** catch of finfish bycatch in 1000s of metric tonnes	• Excluding billfish and tuna • Catch estimates based on observer data, excluding small-scale domestic fisheries of Indonesia, Vietnam, the Philippines, and temperate water purse seiners	
	Estimated **Longline** catch of finfish bycatch in millions of individuals	• Catch estimates based on observer data, excluding domestic fisheries of Indonesia, Vietnam and the Philippines, and former shark-targeted fisheries in Papua-New Guinea and Solomon Islands	
Annual Billfish Bycatch	Estimated **Purse Seine** catch of billfish bycatch in 1000s of individuals from unassociated and associated sets	• Catch estimates based on observer data, excluding small-scale domestic fisheries of Indonesia, Vietnam, the Philippines, and temperate water purse seiners	
	Estimated **Longline** catch of billfish bycatch in millions of individuals	• Catch estimates based on observer data, excluding domestic fisheries of Indonesia, Vietnam and the Philippines, and former shark-targeted fisheries in Papua-New Guinea and Solomon Islands	
Annual Shark Bycatch	Estimated **Unassociated Purse Seine** catch of sharks in 1000s of individuals	• Catch estimates based on observer data, excluding small-scale domestic fisheries of Indonesia, Vietnam, the Philippines, and temperate water purse seiners	
	Estimated **Associated Purse Seine** catch of sharks in 1000s of individuals	• Catch estimates based on observer data, excluding small-scale domestic fisheries of Indonesia, Vietnam, the Philippines, and temperate water purse seiners	
	Estimated **Longline** catch of sharks in millions of individuals	• Catch estimates based on observer data, excluding domestic fisheries of Indonesia, Vietnam and the Philippines, and former shark-targeted fisheries in Papua New Guinea and Solomon Islands