SCIENTIFIC COMMITTEE
EIGHTEENTH REGULAR SESSION

ELECTRONIC MEETING
10-18 August 2022

ECOSYSTEM AND CLIMATE INDICATORS

WCPFC-SC18-2022/EB-WP-01

SPC-OFP

Executive Summary

1. This Working Paper updates SC18 on progress regarding development of the candidate ecosystem and climate indicators for the Western and Central Pacific Ocean (WCPO).

2. Candidate indicates are proposed and summarised in Annex 2.

3. SC18 is advised that while it has developed criteria for developing and testing candidate indicators it has not yet discussed and agreed upon a process for adopting indicators and communicating trends and trigger points derived from those indicators (either to WCPFC or external stakeholders)

4. The working paper provides some options for addressing this gap. These include:

   i. Working papers are presented to the Scientific Committee on an occasional basis, at which point the Committee can assess them against the above criteria. This would represent the *status-quo* arrangement. Note that this option would not provide any clarity on the use of these indicators.

   ii. Make "Ecosystem and Climate Indicators" a standing agenda item of the Ecosystem and Bycatch Theme. 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. It would also facilitate discussion on how best the Scientific Committee would like adopted indicators to be presented (e.g. report cards, dashboards, annual working papers, etc).

   iii. Establish the development and testing of "Ecosystem and Climate Indicators" as a project of the Scientific Committee. This would provide a mechanism for the Scientific Committee to easily track its progress towards evaluating and adopting candidate indicators. A draft Terms of Reference for such a project is provided as Annex 3 to this working paper.

5. The SSP considers both options ii and iii as preferred approaches as they allow for greater transparency and efficiency for future reporting.

Recommendations

6. SC18 is invited to:

   - note that the SSP has selected a suite of candidate indicators for monitoring ecosystems and climatic trends across the WCPO;
   - direct the SSP to proceed (or not) with the development and testing of these candidate indicators;
   - provide clarity on SC's preferred process for evaluation and adoption/endorsement of the candidate indicators by the Scientific Committee;
   - consider the options for communicating ecosystem and climate change impacts to WCPFC (e.g. combined with status of stocks reporting) and external stakeholders and interest groups.

Background

7. This Working Paper updates SC18 on progress regarding development of the candidate ecosystem and climate indicators for the Western and Central Pacific Ocean (WCPO).

8. The Scientific Committee has been considering the application of ecosystem indicators to assist with advice generation on the impacts of fisheries targeting tuna and tuna-like species on the broader pelagic ecosystem since SC11 in 2015. The rationale for and potential design and testing criteria for ecosystem indicators were agreed at SC12 (including a provisional workplan for their development – see Annex 1). Candidate indicators have subsequently been presented to the Science Committee since SC15, including those proposed for application in other ocean basins (see SC15-EB-WP-12 and SC16-EB-IP-07).

9. SC16-EB-IP-07 and SC17-EB-IP-09 presented candidate ecosystem and climate indicators that can be established using existing data sources and collection programmes, rather than proposing new activities that may need additional resources. The indicators proposed are in addition to those already used by the Scientific Committee to report on target stocks, and are classified under one of the following three banners: (a) Environment and Fishing Effort; (b) Target Species Catch and Distribution; and (c) Biology and Bycatch.

10. Annex 2 to this working paper presents the candidate indicators proposed in SC17-EB-IP-09.

11. SC17-EB-IP-09 proposed that the regular reporting of adopted indicators could form the basis of a report card on WCPO ecosystem and climate states. Such report cards would assist WCPFC with provision of information that supports its application of EAFM and the implementation of the WCPFC climate resolution. Digitalising the report card format into a dashboard style tool would also allow varying spatial and temporal resolutions of the indicators to be more efficiently communicated. The Government of New Zealand has provided support to the SSP to further develop candidate climate indicators to facilitate WCPFC's capacity to adapt to and mitigate against climate change.

12. Through appropriate design, adopted indicators are also expected to identify when MSE Exceptional Circumstances are occurring thereby providing the Scientific Committee with key information for implementing harvest strategies as part of the regular monitoring strategy (i.e. where climate and ecosystem changes fall outside the ranges of uncertainty against which a harvest strategy was tested and whether specified ecosystem objectives are being achieved), and hence whether that strategy needs to be revisited. Similarly, well designed indicators should provide information on the pace at which physical properties of the WCPO are approaching climate change induced tipping points. The later will not only be important for adapting the region's tuna fisheries to the impacts of climate change but also provide necessary information for WCPFC members to voice the impact of climate change on tuna fisheries at global forums such as UNFCCC.

13. Once adopted, key ecosystem and climate indicators will also provide the Scientific Committee with the capability to report on ecosystem and climate change impacts in its annual reporting to WCPFC. Hence, adopted ecosystem and climate indicators are expected to be regularised as standard tools for monitoring the status of WCPFC fisheries and ecosystems.

14. The restricted online nature of recent Scientific Committee meetings (SC16 and SC17) has provided little opportunity for review and discussion on these candidate indicators and the process for adopting them as part of a regular report to the Scientific Committee.

Process for adopting indicators

15. SC12 noted that developing a thorough understanding of how to interpret potential indicators, their appropriate reference levels and baselines, and how reliable they are for prediction were critical steps for indicator adoption by the WCPFC Scientific Committee (SC). Criteria for developing and testing candidate indicators has subsequently been proposed to the Scientific Committee:

    - science and data based;
    - characterize the states and trends of WCPFC marine ecosystems with respect to fishing activity and/or climate (including reference levels and baselines);
    - reflect well-defined processes underlying fishing activity and fishery responses to climate;
    - responsive to changes attributable to fishing pressure and climate (ie. minimal time-lags and capability to provide early warning);
    - estimable on a routine basis with a historical data time-series available;
    - cost-effectiveness;
    - scalable across national, sub-regional and regional scales;
    - linked to existing WCPFC models and decision-making processes (for inclusion in MSE scenarios, validation of predictions and testing of model assumptions);
    - can be routinely estimated by members without reliance of the Science Service Provider.

16. The Scientific Committee has not discussed a process for its adoption/endorsement of candidate ecosystem and climate indicators. Three possible options for adoption are:

    i. Working papers are presented to the Scientific Committee on an occasional basis, at which point the Committee can assess them against the above criteria. This would represent the *status-quo* arrangement. Note that this option would not provide any clarity on the use of these indicators

    ii. Make “Ecosystem and Climate Indicators” a standing agenda item of the Ecosystem and Bycatch Theme. 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. It would also facilitate discussion on how best the Scientific Committee would like adopted indicators to be presented (e.g. report cards, dashboards, annual working papers, etc).

    iii. Establish the development and testing of “Ecosystem and Climate Indicators” as a project of the Scientific Committee. This would provide a mechanism for the Scientific Committee to easily track its progress towards evaluating and adopting candidate indicators. A draft Terms of Reference for such a project is provided as Annex 3 to this working paper.

17. The SSP recommends that the Scientific Committee considers options ii and iii as its preferred way forward as both provide transparency and efficiency for reporting to WCPFC and for information requests from external stakeholders. Options ii and iii may also facilitate greater contribution of candidate indicators from WCPFC members and stakeholders in addition to the work of the SSP.

18. A formal Scientific Committee project would also facilitate future discussions if a member or the SSP required any budgetary support for development and testing of candidate indicators. There

is currently no budgetary request from the SSP to further develop and test the candidate indicators presented in Annex 2 of this working paper.

Recommendations

19. SC18 is invited to:

- note that the SSP has selected a suite of candidate indicators for monitoring ecosystems and climatic trends across the WCPO;
- direct the SSP to proceed (or not) with the development and testing of these candidate indicators;
- provide clarity on SC's preferred process for evaluation and adoption/endorsement of the candidate indicators by the Scientific Committee;
- consider the options for communicating ecosystem and climate change impacts to WCPFC (e.g. combined with status of stocks reporting) and external stakeholders and interest groups.

Annex 1. Provisional Ecosystem Indicators Workplan proposed at SC12

Table 1: Proposed approach for the design and testing of WCPO ecosystem indicators for use by WCPFC (note that the last two columns are indicative only and intended to be developed over time).

<table>
<tr><th>Task</th><th>Timeframe</th><th>Concurrent SC Work</th><th>Concurrent Activities</th></tr>
<tr><td>Conduct a technical review of other RFMO ecosystem indicator work, and broader development in ecosystem indicators</td><td>Jan-Apr 2017</td><td rowspan="8">Improving quality of observer data

Improving quality and comprehensiveness of fisheries data

Expanding range of data collected

Developing MSE for the tropical tuna species and albacore

Implementation of the shark research plan

Implementation of the Strategic Research Plan

Biological and ecological studies of the tuna species</td><td rowspan="8">Improving the use of ecosystem models to advise management

Increasing the monitoring of catch and discards for bycatch species

Expanding fisheries monitoring programmes to include prey species

Adding spatial components to ecosystem models

Exploring changes in tuna biology over time

Exploring changes in tuna diet through time

Developing SEAPODYM and in particular management applications

Enhancing biological data collection and the tuna tissue bank</td></tr>
<tr><td>Expert workshop to develop a range of candidate ecosystem indicators for the WCPO</td><td>May 2017</td></tr>
<tr><td>SC discussion on the range of candidate ecosystem indicators for the WCPO from the expert workshop</td><td>Aug 2017</td></tr>
<tr><td>Engage broader stakeholder base in discussion on the range of candidate ecosystem indicators</td><td>Sep – Dec 2017</td></tr>
<tr><td>Compilation of data and analyses to inform testing of ecosystem indicators</td><td>Oct 2017-Jan 2018</td></tr>
<tr><td>Expert workshop to test the refined range of candidate ecosystem indicators for the WCPO</td><td>Jan-Feb 2018</td></tr>
<tr><td>Review indicators and data requirements and integrate into WCPFC fisheries and ecosystem monitoring programme</td><td>Feb 2018-Apr 2018</td></tr>
<tr><td>SC review of the range of candidate ecosystem indicators for the WCPO</td><td>Aug 2018</td></tr>
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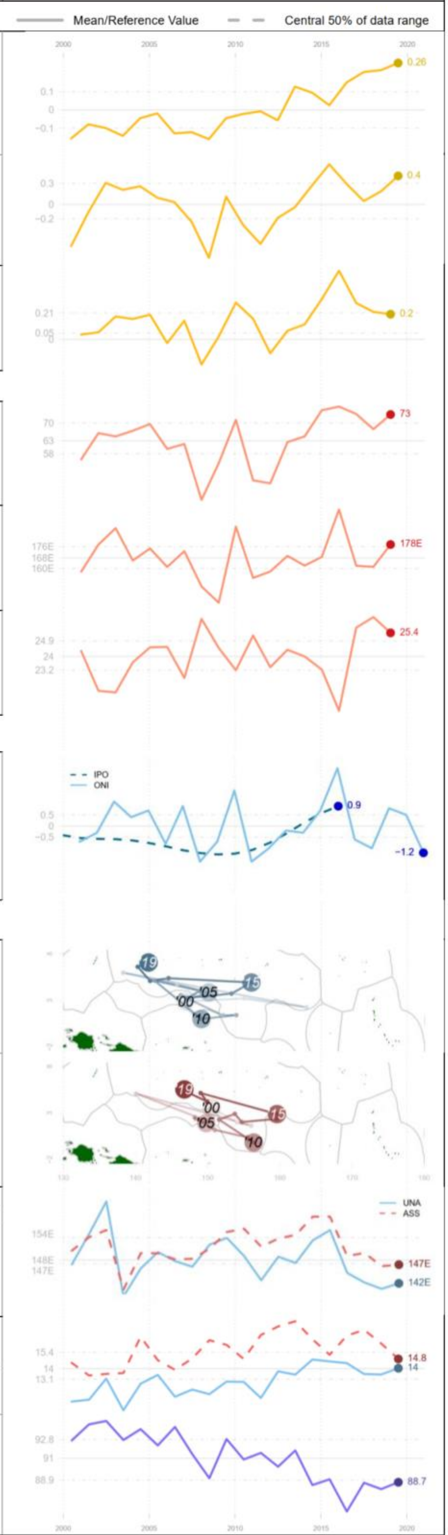
Annex 2 Candidate Ecosystem and Climate Indicators presented to SC17 (see SC17-EB-IP-09)

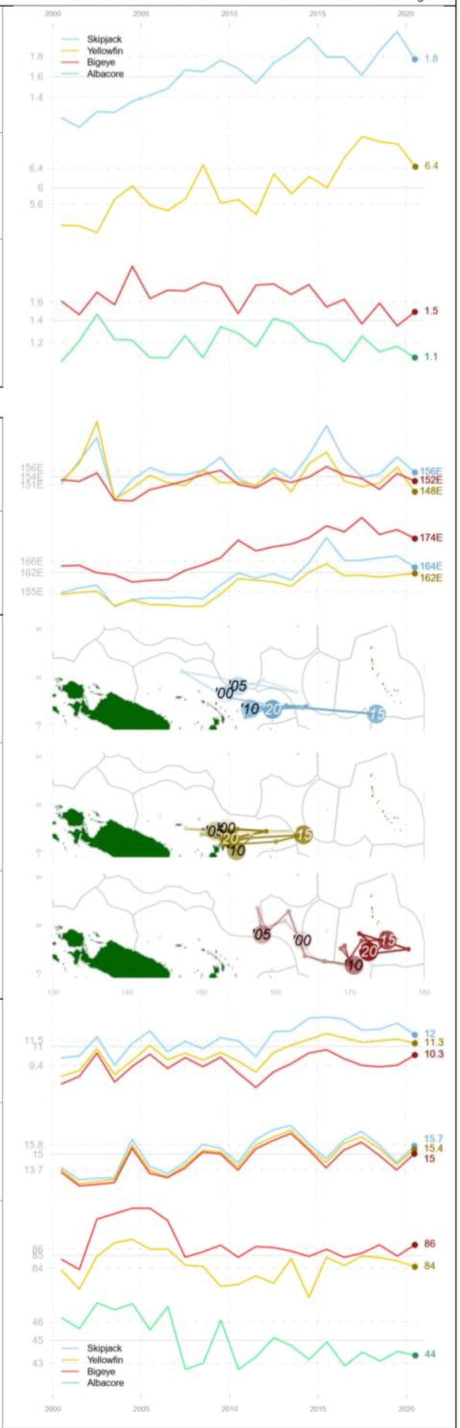
Report Card 1. Environment and Fishing Effort Indicators

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 2000-2019	
	Mean annual SST anomaly (°C) across **WCPO equatorial zone**	• Derived from ocean models • Equatorial zone 5°S-5°N • Anomaly from mean temperature 2000-2019	
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 km²	• 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 • Long-term IPO changes only calculable to 2016	
Fishing Effort Indicators (ANNEX 1 - A.4)			
Centre of Purse Seine Effort	Annual centre of gravity for **Unassociated Purse Seine** effort, with every fifth year and the terminal year denoted with a point (2000-2019)		
	Annual centre of gravity for **Associated Purse Seine** effort, with every fifth year and the terminal year denoted with a point (2000-2019)		
Annual, Longitudinal Centre of Purse Seine Effort	Mean longitudinal centre of gravity of purse seine effort	• Purse seine effort is disaggregated into unassociated free-school (UNA) and associated (ASS) sets. • Associated (ASS) 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 km²	• The sum of the area of 1° x 1° cells with at least one purse seine set, aggregated annually	
	Total area occupied by **Longline** fleet annually, in millions of km²	• The summed area of 5° x 5° cells with at least one longline set, aggregated annually	

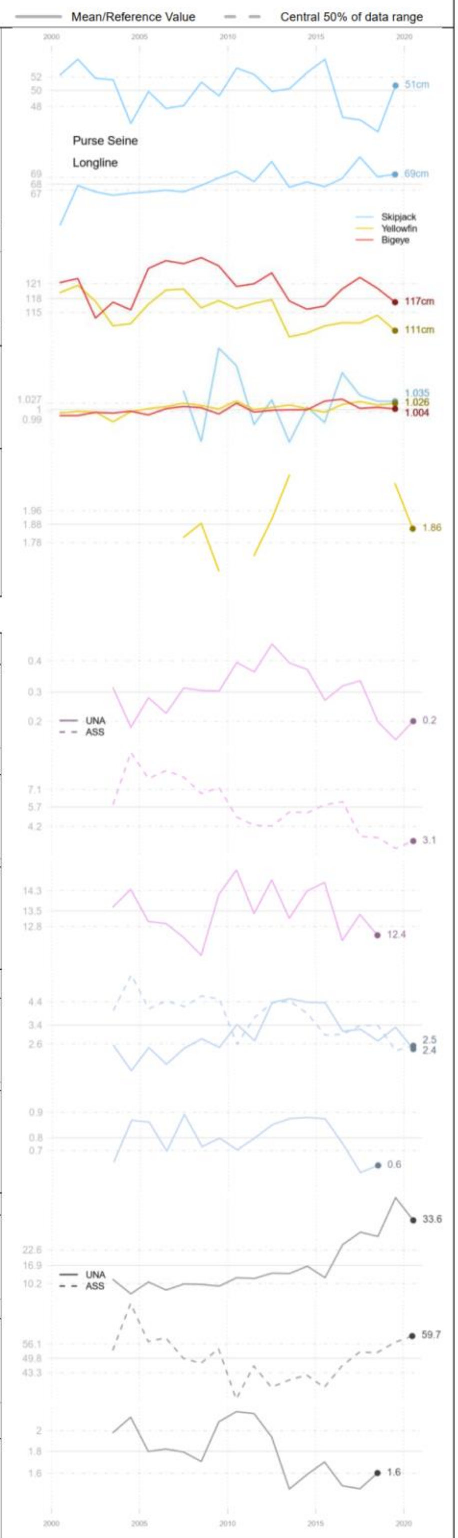


Report Card 2. Target Species Catch and Distribution Indicators

Indicator	Description	Notes	Time-series
Target Species Catch (ANNEX 1 - A.5)			Mean/Reference Value — Central 50% of data range
Annual Tuna Catch	Total **Skipjack** catch for entire WCPFC-CA, in millions of tonnes	▪ Data from all fishing gears combined ▪ See Hare et al. (2021) [SC17-SA-IP-15] 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. (2021) [SC17-SA-IP-15] 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. (2021) [SC17-SA-IP-15] for a compilation of all fishery indicators for bigeye and South Pacific albacore	
Target Species Distribution (ANNEX 1 - A.6)			
Longitudinal Centre of Purse Seine Catch	The mean, annual longitude of **Unassociated Purse Seine** catch for skipjack, yellowfin and bigeye tuna (colours as above)		
	The mean longitude of **Associated Purse Seine** catch for skipjack, yellowfin and bigeye tuna (colours as above)		
Centre of Purse Seine Catch	Annual centre of gravity for associated purse seine catch of **Skipjack** tuna, with every fifth year highlighted with a point (2000-2020)		
	Annual centre of gravity for associated purse seine catch of **Yellowfin** tuna, with every fifth year highlighted with a point (2000-2020)		
	Annual centre of gravity for associated purse seine catch of **Bigeye** tuna, with every fifth year highlighted with a point (2000-2020)		
Annual Area of Target Species Catch	Annual area of **Unassociated Purse Seine** Target Species catch	▪ The summed area of 1° x 1° cells where skipjack, yellowfin and bigeye tuna were captured by UNA sets	
	Annual area of **Associated Purse Seine** Target Species catch	▪ The summed area of 1° x 1° cells where skipjack, yellowfin and bigeye tuna were captured by ASS sets	
	Annual area of **Longline** Target Species catch	▪ The summed area of 5° x 5° cells where yellowfin, bigeye and South Pacific albacore tuna were captured by longline	



Report Card 3. Biology and Bycatch Indicators

Indicator	Description	Notes	Time-series
Target Species Condition (ANNEX 1 - A.7)			
Mean Length of Target 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 2000 to 2019, for each species separately	
Mean Fat Content of Sampled Tuna	Mean fat content (%) as measured by fatmeter during annual PTTP research cruises informing on tuna condition: fatter fish being considered in better condition	▪ Yellowfin tuna measuring 40 to 60 cm fork length ▪ Years available: 2007-2009, 2011-2013, 2019-2020 ▪ Sample size varies considerably by year (range *n* = 9-264, mean *n* = 110)	
Bycatch Species (ANNEX 1 - A.8)			
Annual Finfish Bycatch	Estimated **Unassociated Purse Seine** catch 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 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 species 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 in 1000s of individuals, separated between associated and un-associated purse seine.	▪ 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 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 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 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	

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

Environment and Fishing Effort 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 2000-2019. 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 main text). 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 2000-2019 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 warm pool 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.

A.4 *Fishing Effort indicators*

Data to characterize trends in fishing effort were extracted from SPC's S_BEST and L_BEST databases from 2000-2019, for purse seine (PS) and longline (LL) catch and effort data, respectively. These databases contain aggregated, raised fishing effort across the WCPFC Convention Area. 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 and season (i.e. year-quarter) for each fishing mode i.e. 'unassociated' free-school sets (UNA) versus 'associated' sets (ASS). It should be noted that for this analysis, associated (ASS) 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.

Target Species Catch and Distribution indicators

A.5 *Target Species Catch*

These indicators describe trends in annual catch estimates (in mt) of the four main tuna species (skipjack, yellowfin, bigeye and albacore) targeted within the WCPFC Convention Area, between 2000 and 2020, 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. (2021) [SC17-SA-IP-15] for a compilation of all fishery indicators for these target tunas.

A.6 *Target Species Distribution*

This set of indicators describe annual trends in the central tendency and distribution of catch of the four main tuna species (skipjack, yellowfin, bigeye and albacore) targeted by purse seine and longline fisheries within the WCPFC Convention Area, between 2000 and 2020, inclusive. Data for the calculations were extracted from the same sources described in section A.5. We elected to focus again on the purse seine and longline data only as they represent the major gear sectors for the region.

The indicators selected were kept consistent with those used to explore annual trends in fishing effort (see section A.4). We defined the central tendency of purse seine fishing catch by the 'centre of gravity' of catch in metric tonnes (mt). This was calculated by year for each purse seine fishing mode separately (i.e. UNA versus ASS sets). For the reasons stated in section A.4, we decided not to present central tendency metrics for the longline catch.

Finally, we used the S_BEST and L_BEST datasets to assess annual trends in the area over which tuna catch occurred within the WCPFC Convention Area. The number of unique 1° x 1° cells in which purse seine catch occurred, and the number of 5° x 5° cells in which longline catch occurred were summed by year, and used to calculate the annual area of catch in km^2. Results are presented for each gear type, purse seine fishing mode, and species separately.

Biology and Bycatch Indicators

A.7 *Target Species Condition*

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 Convention Area between 2000 and 2019, inclusive. The length data were 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. 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. 2021 [SC17-ST-IP-05] for an update on progress on this conversion factor work.

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 Convention Area between 2000 and 2019, inclusive. Length data were again 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.4) 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 20-year time series. As for yellowfin and bigeye, length measurements were converted to fork length (UF) in cm where required using published conversion factors.

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 Convention Area between 2000 and 2019, 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 strong sample sizes (skipjack: n = 31,360; yellowfin: n = 1,040,446; bigeye: n = 914,552), and 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 2000 to 2019 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 this report card.

Mean fat content represents the percentage of lipids in the tuna flesh. 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. Fat content of fish is measured during research tagging cruises. Fat content is dependent on fish size; hence to avoid introducing bias in the fat content indicator, only yellowfin measuring 40-60cm fork length were used to calculate annual fat content.

A.8 *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 Convention Area. 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 Convention Area, 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.

Annex 3 Draft Terms of Reference: Ecosystem and Climate Indicators

Objectives

- Develop and test candidate ecosystem and climate indicators to track the impact of climate and ecosystem changes on WCPFC fisheries and ecosystems.
- Provide technical advice to the Scientific Committee on the suitability of criteria used for testing and evaluating the performance of candidate indicators.
- Support the Scientific Committee in developing tools to communicate ecosystem and climate change impacts to WCPFC and external stakeholders and interest group.

Rationale

Fisheries management decisions are, at their simplest, informed risk management. Data describing fisheries are collected. Scientists, economists, compliance analysts, and the like derive information from the data and bring their respective knowledge to bear to put that in front of fisheries managers. Those managers are then able to use that knowledge and make decisions which minimise risk – on many issues including for example stock sustainability, the population status of species of special interest, and fishers' incomes.

In stock assessment we are constantly striving – through obtaining better data, developing a greater understanding of the ecology of the target species, and improving our modelling approaches – to develop greater precision as to stock status and at the same time reduce the biases in our predictions of stock status. With greater precision we are able to both better specify the range of plausible outcomes resulting from decisions, and reduce the risk in those decisions.

But tuna do not live in isolation from the ecosystem which supports them. At its simplest, if the system in which they live is sick, the tuna population cannot thrive despite the wisest decisions based on single-species stock assessment. To make truly wise decisions we need to consider the ecosystem with the stock. Even in their simplest implementation ecosystem indicators should enable more precise specification of the range of decisions leading to desired or effective outcomes, and reduce the risk of bad outcomes from those decisions through better understanding of the cause of potential stock assessment biases. Especially for the longer-lived tunas, ecosystem indicators should increasingly provide early warning of when issues may arise. Such forecasts allow time for management response in near real-time rather than trying to catch up years later. This will be particularly important as we move to making decisions in a Harvest Strategy framework and detecting when climate and ecosystem changes fall outside the ranges of uncertainty against which a management procedure was tested, and whether broader ecosystem objectives are being met.

WCPFC has already recognised the importance of preparing the region to adapt to the emerging impacts of climate change (see Resolution 2019-01 "Resolution on Climate Change as it relates to the Western and Central Pacific Fisheries Commission"). Well-designed climate indicators should provide information on the pace at which physical properties of the WCPO are approaching climate change-induced tipping points. This will not only be important for adapting the region's tuna fisheries to the impacts of climate change but also provide necessary information for WCPFC members to voice the impact of climate change on tuna fisheries at global forums such as UNFCCC.

In addition to the role that ecosystem and climate indicators play in assisting with the formulation of management advice and decisions, they can also be effective in communicating information within WCPFC's membership and to external stakeholders and interest groups.

Assumptions

- WCPFC and the Scientific Committee continue to require the development of ecosystem and climate indicators.
- External funds remain available to support the development, testing and analyses of ecosystem and climate indicators.

Scope of Work

- Technical analyses to develop and test candidate indicators.
- WCPFC member and expert workshops to refine indicators.
- Scientific Committee Reporting.
- Routine preparation of adopted indicators
- Development of tools forcommunication to WCPFC and wider stakeholders.

Timeframe

A timeframe of five-years is proposed for this project, after which preparation of adopted indicators should be regularised into the work of the Scientific Committee or an alternative approach will need to be considered to progress the work (if minimal progress has been achieved).

Budget

This is a no-cost project for 2023. Any budgetary support required by the SSP or members beyond 2023 is subject to approval once specific workplans and proposal are reviewed and prioritised by the Scientific Committee.