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WCPO ECOSYSTEM AND CLIMATE INDICATORS FROM 2000 TO 2020

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Paper prepared by:

Oceanic Fisheries Programme, Pacific Community

Contributors in alphabetic order: Valerie Allain, Steven Hare, Jed Macdonald, Pauline Machful, Simon Nicol, Joe Scutt Phillips, Annie Portal, Tiffany Vidal, Peter Williams

Ocean Fisheries Programme (OFP), Pacific Community (SPC), Nouméa, New Caledonia

EXECUTIVE SUMMARY

Background

1. This Information Paper updates SC17 on progress regarding development of the candidate ecosystem and climate indicators for the Western and Central Pacific Ocean (WCPO) presented to SC16 (see Allain et al. 2020) [SC16-EB-IP-07].

2. The list of 27 indicators proposed by Allain et al. (2020) has been further refined and expanded, and here we provide "Report Cards" for a suite of preliminary indicators, each classified under one of the following three banners:

Report Card 1: *Environment and Fishing Effort* (15 indicators)

Report Card 2: *Target Species Catch and Distribution* (18 indicators)

Report Card 3: *Biology and Bycatch* (17 indicators)

3. The Report Cards were designed to:

i. illustrate the temporal evolution of these 30 ecosystem and climate indicators across the WCPO over the past two decades in a simple, intuitive format; and

ii. provide a reference guide for monitoring changes in these indicators that can be readily updated as new data comes to hand.

4. 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).

5. Our purpose here is to provide a first example of the type of information that could be easily updated on a yearly basis. Minimal commentary is provided on how these indicators might reflect changes in the system, and the implications of such changes for management.

6. Before commencing the work to make these links, we are seeking advice from SC17 on the utility and relevance of this suite of indicators for further development.

7. Note also that the indicators considered here are in addition to standard indicators used by the SC to report on target stocks (e.g. CPUE trends, effort creep) and bycatch species, and we refer readers to the following papers for updates on these (Peatman and Nicol 2020, 2021; Hare et al. 2021; Vidal et al. 2021).

Recommendations

SC17 is invited to:

i. note the progress towards developing candidate indicators for monitoring ecosystems and climatic trends across the WCPO;

ii. provide guidance on the utility and relevance of this suite of indicators for further development (i.e. defining baselines, interpretation, predictive capabilities); and

iii. provide guidance on the use of a "Report Card" framework for communicating ecosystem and climate indicators to WCPFC and other interested parties.

INTRODUCTION

Following discussions at SC12 and SC15, and papers arising from these meetings (Juan-Jordá et al. 2019a [SC15-EB-WP-12], b), the development of informative indicators for monitoring ecosystems and climatic trends across the Western and Central Pacific Ocean (WCPO) has emerged as a 'moderate priority' for the WCPFC Scientific Committee (SC).

In an Information Paper to SC16, Allain et al. (2020) [SC16-EB-IP-07] proposed a set of candidate ecosystem and climate indicators that can be developed for the WCPO using existing data sources and collection programmes. The ecosystem indicators defined within that candidate set were selected based on a scheme outlined by Queirós et al. (2016) (see *Criteria for selecting ecosystem and climate Indicators* below) and applied by Juan-Jordá et al. (2019a, b), the latter papers prioritising ecosystem indicators of relevance to tuna RFMOs (specifically ICCAT and IOTC). Given the adoption of the WCPFC Resolution on Climate Change in 2019 (Resolution 2019-01), Allain et al. (2020) also proposed 10 additional local- and regional-scale climate indicators to facilitate provision of advice on climate impacts, should such requests arise.

This Information Paper extends the work of Allain et al. (2020) in two areas. First, through the refinement and expansion of the original indicator set to encompass 50 ecosystem and climate indicators. And second, through the creation of "Report Cards" designed to illustrate trends in these indicators across the WCPO over the past two decades in a simple, intuitive format, that can be easily updated as new data arrives.

We classify each of the 50 indicators presented in the present paper under one of three banners: *Environment and Fishing Effort* (15 indicators); *Target Species Catch and Distribution* (18 indicators); and *Biology and Bycatch* (17 indicators), with a Report Card dedicated to each banner.

Criteria for selecting ecosystem and climate Indicators

To briefly reiterate on the criteria used by both Allain et al. (2020) and the present paper to select candidate indicators, the indicators we chose were required to:

i. be based on empirical data;
ii. characterise the states and trends of WCPFC marine ecosystems with respect to fishing activity and/or climate;
iii. reflect well-defined processes underlying fishing activity and fishery responses to climate;
iv. be responsive to changes attributable to fishing pressure and climate (i.e. minimal time-lags and capacity to provide early warning);
v. be calculable on a routine basis with available time-series data;
vi. be cost-effective;
vii. be scalable across national, sub-regional and regional scales;
viii. be linked to existing WCPFC models and decision making processes (i.e. for inclusion in MSE scenarios, validation of predictions and testing of model assumptions);
ix. be calculable and interpretable by WCPFC members without direct reliance on the Scientific Services Provider.

Selected indicators, their calculations, and scales

Fifty indicators were chosen for the Report Cards, based around, and in some cases extending upon, the 27 indicators originally proposed in SC16-EB-IP-07 (see Allain et al. 2020 for a complete list). These indicators are presented as a preliminary attempt to capture pertinent trends of interest to WCPFC member countries and territories, in the hope that they may be further developed as useful tools for monitoring ecosystem condition and climatic patterns in the region in the near- to medium-term.

Details on how each indicator was calculated and links to the code used to produce them are found in ANNEX I. Unless otherwise stated in the Report Cards, all indicators are calculated at the spatial scale of the WCPFC Convention Area or WCPO region (Figure 1) and cover the 20-year time period between 2000 and 2019, inclusive, or the 21-year time period from 2000 to 2020, if 2020 data were available. Anomaly indicators (e.g. mean annual SST anomaly) are calculated from the 2000-2019 average.

Finally, we stress the preliminary nature of this work, and welcome feedback from SC17 and the WCPFC members on the utility and relevance of the suite of indicators we present here for their specific applications.

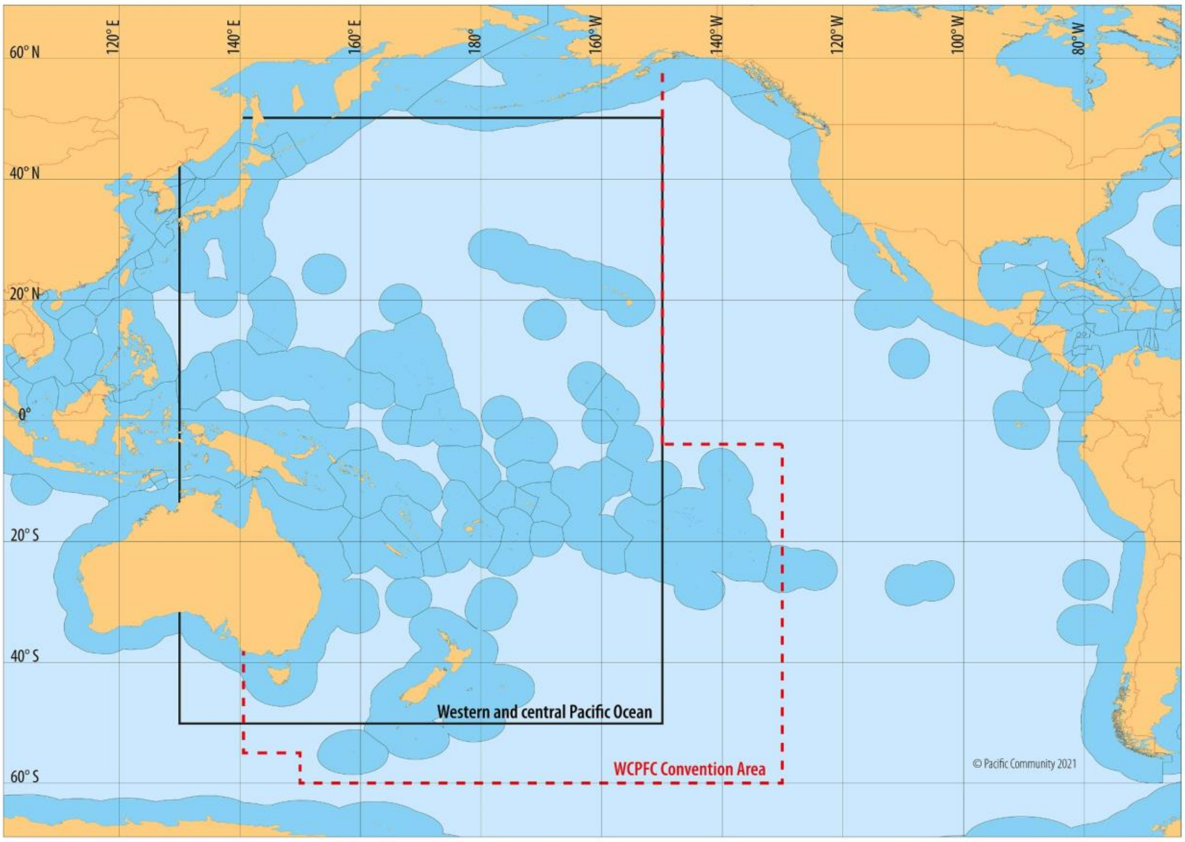
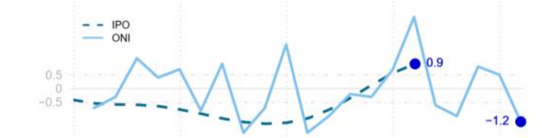
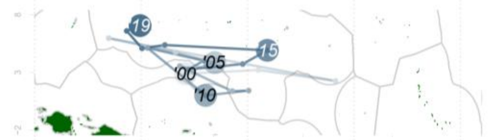
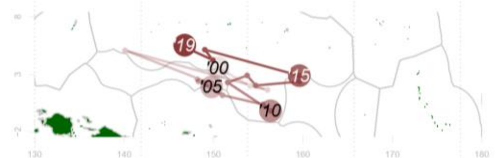
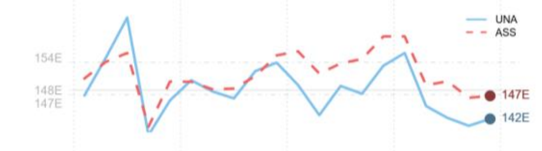
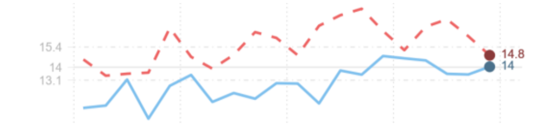
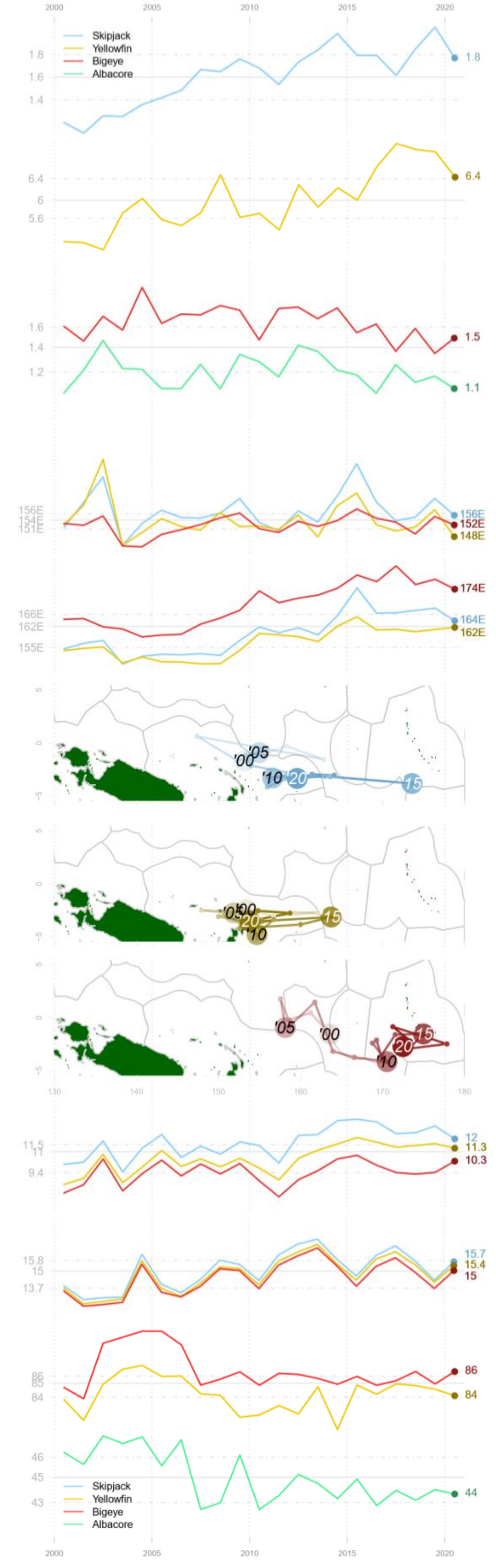


Figure 1. Map of the Pacific Ocean showing the extents of the WCPFC Convention Area and the Western and Central Pacific Ocean (WCPO).

Report Card 1. Environment and Fishing Effort Indicators

Indicator	Description	Notes	Time-series
Sea Surface Temperature Anomalies (ANNEX 1 - A.1)			Mean/Reference Value — Central 50% of data range
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	

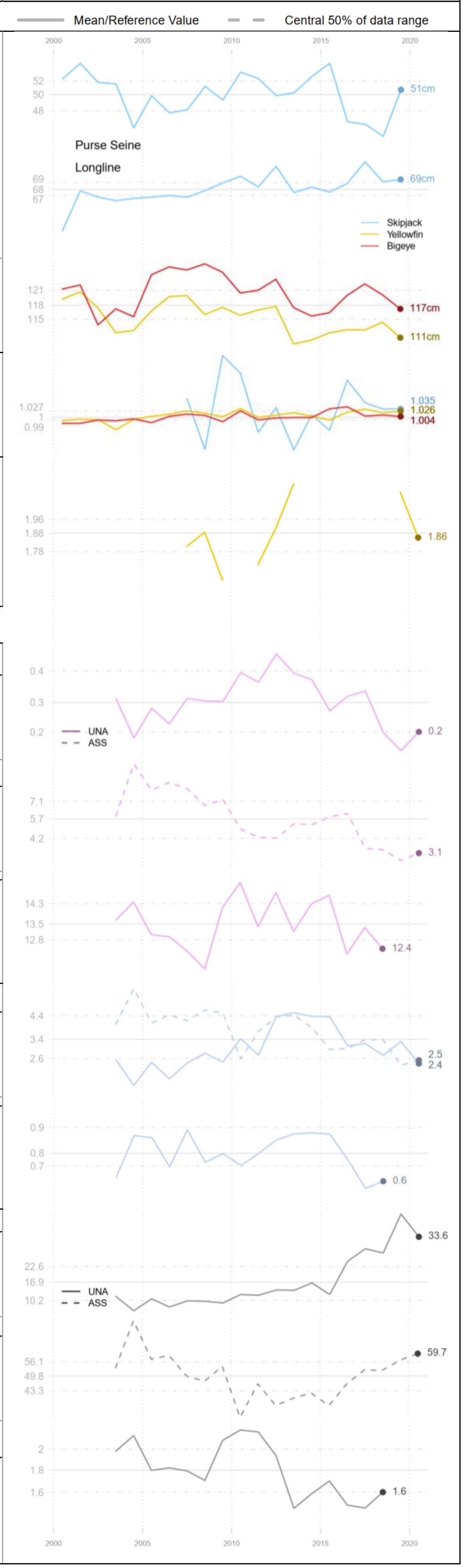
Report Card 2. Target Species Catch and Distribution Indicators

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
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

Time-series



RESULTS and DISCUSSION

The purpose of this Information Paper, and the Report Cards documented within, is to present a suite of potentially useful indicators for quantifying trends in the climate and oceanic ecosystem status of the WCPO. Through the presentation of metrics that track environmental, fishery-related and biological changes at multiple scales, these Report Cards aim to provide an initial framework for identifying informative indicators of change in regional climate and ecosystem processes. As noted in the Introduction, this paper constitutes a first attempt at compiling and presenting data for the selected indicators, and we recommend that further work follows to assess each indicator's utility and relevance to marine resource management. Below we provide a brief summary of the patterns seen in this first reporting year.

Environment and Fishing Effort Indicators (Report Card 1)

Accurate monitoring of environmental variables is important not only for the assessment of climate change patterns, but also to provide oceanographic context to the observed changes in other indicators. Our selected environmental indicators illustrate that warming of the WCPO area has continued since the strong El Niño event occurring during 2015-2016, although the temperature of the warm-pool itself has not reached the same level as that period. The size of the warm-pool has continued to increase since 2010, while the eastern extent has not shifted markedly over the previous 20 years, but continues to fluctuate. It appears that the increased size of the warm-pool is caused by a greater latitudinal extent. The effects of the most recent La Niña event (2020-2021) are not quantified as of yet, but we note that this follows two consecutive years of ENSO (El Niño Southern Oscillation) positive phases.

When considered in conjunction with the environmental trends, empirically-derived indicators that capture temporal shifts in fishing effort distribution can help us benchmark the impacts of fishing-climate interactions on the spatio-temporal distribution of tuna and bycatch species. For the WCPO purse seine fleet, fishing effort has centred on the western area of the WCPO over the past two decades, with a shift further north in the recent years. The area occupied by the purse seine fleet has increased gradually through time, with effort on both associated and unassociated sets spread over a greater area in the recent decade compared to the 2000-2010 period. The area occupied by the WCPO longline fishery has decreased since 2000, with a sharper decline observed since 2010. The area fished has stabilised somewhat between 2016 and 2019.

Target Species Catch and Distribution Indicators (Report Card 2)

Temporal trends in target species' abundance drawn from fishery data can help chart fishing and management-related impacts, while the spatial distribution of fisheries catch can be interpreted as a proxy of both target and bycatch species' distributions, notwithstanding the biases linked to the non-random distribution of fishing effort and gear selectivity. Integrating metrics that monitor the central tendency and spread of the catch distribution with those that trace catch trends, environmental change (see Report Card 1) and species' biological parameters (see Report Card 3) may provide valuable multi-source inference on species' responses to ecosystem and climatic variability.

In Report Card 2, we monitored the annual total catch from all gears for the four principal tuna species (i.e. skipjack, yellowfin, bigeye, albacore) targeted in WCPO fisheries. The catch of skipjack and yellowfin in the WCPFC Convention Area has increased over the past 20 years, with ~1.8 million and ~640 thousand tonnes captured, respectively, in 2020. Bigeye and South Pacific albacore catches were far lower, but have remained relatively stable across the same time period. We refer readers to Hare et al. (2021) [SC17-SA-IP-15] for a detailed appraisal of fishery indicators for these target tuna species.

We also tracked longitudinal trends and central tendency of the purse seine catch (in metric tonnes) for skipjack, yellowfin, bigeye. Annual trends in catch centres of gravity were similar among the three species within each fishing mode; the central tendency of bigeye catch in associated sets typically falling about 10° to the east of the skipjack and yellowfin catch centres. The centres of gravity of catch from unassociated purse seine sets were located largely to the west and slightly north of catch centres for associated sets. We also noted a gradual yet consistent eastward shift in catch centres of gravity for associated sets for all three tunas, while catch from unassociated sets showed no such pattern. The catch area for the purse seine fishery has increased in the past decade compared to the 2000-2010 period, with catch area for associated sets fluctuating at approximately 5-year intervals. The catch area for the WCPO longline fishery for yellowfin and bigeye tuna has remained relatively stable over the past 10 years, following the highpoint in the mid-2000s. The smaller catch area for South Pacific albacore has decreased since the early 2000s but has stabilised at or above ~ 40 million km^2 over the most recent decade.

Biology and Bycatch Indicators (Report Card 3)

The indicators presented under the 'Target Species Condition' subheading were designed to detect biological shifts in the ecosystem. Our analysis of mean length and relative condition for longline-caught yellowfin and bigeye tuna revealed a trend towards shorter but 'fatter' tuna, with the two species tracking each other in both the length and condition indicators. Skipjack mean length, derived from purse seine and longline captures, and mean relative condition derived from longline captures, were variable across the time series, with no clear temporal trends apparent. Data on the fat content of tuna can inform on the quality and quantity of prey available in the environment, and here we present the first data derived from 'Fatmeter' measurements on yellowfin tuna. Though detailed interpretation of these data is not possible given the gaps in the time series, we note that Fatmeter data collection is being expanded and now forms a regular part of SPC tuna research cruise activities. We highlight also that work on developing other indices of fish condition (e.g. stomach fullness) is ongoing.

Finally, trends in abundance of key bycatch species captured in WCPFC-CA purse seine and longline fisheries were presented as a means to monitor the effects of ecosystem and climatic changes at different trophic levels, as well as gauge the impact of any fisheries management measures (pertaining to bycatch) on these changes. Purse seine catch of finfish (excluding tuna and billfish) and billfish has declined over the past two decades, whereas shark catch has increased over the past five years in both associated and un-associated purse seine sets. Patterns were less clear for the longline catches, though shark catch from longline gear has decreased marginally since 2000 (note the different y-axis scales for purse seine and longline estimates).

CONCLUSIONS

Ultimately, it is hoped that with further development these Report Cards will constitute useful, accessible tools for identifying and tracking key ecosystem and climate indicators that accurately capture both the state of the WCPO marine ecosystem, and the impact of management actions pertaining to marine resource use. Whilst simply monitoring the natural variability of each indicator through time is a worthwhile exercise, the SC has already advised that greater value might lie in exploring connections, either mechanistic or phenomenological, between specific metrics and the management objectives or performance indicators of WCPO fisheries.

To illustrate, several past studies have found evidence for connections between environmental or biological indicators and tuna fisheries, both in the WCPO and in other oceans (e.g. Lehodey et al. 1997; Ravier and Fromentin, 2004; Goñi and Arrizabalaga, 2010). Examples include the observed variability in the distribution of fishing effort in response to ENSO (Lehodey et al. 1997), and fluctuations in skipjack and albacore tuna recruitment estimated by MULTIFAN-CL (Fournier et al. 1998; Hampton and Fournier 2001). that correlate with ENSO and decadal-scale climate indices (Lehodey et al. 2007, 2020). If, for instance, a relationship could be established between the size and temperature of the warm pool and spawning habitat for skipjack tuna, such an index could help inform the estimation of recruitment in the stock assessment, or provide future recruitment scenarios under a management strategy evaluation framework (e.g. Scott et al. 2020).

The breadth of indicators presented in Report Cards 1 to 3 opens opportunities for pursuing such studies at the climate-ecosystem-fisheries interface within the WCPO and beyond. However, to optimise data inputs for progressing such work, we must define the best set of indicators possible for the applications of interest.

To this end, we seek feedback from the WCPFC Scientific Committee and members on the pertinence of the indicators presented here, so that we can prioritise those that are developed further to describe baseline/reference conditions, their predictive capabilities and management interpretation. We also seek guidance on the "Report Card" format as an approach to communicate selected ecosystem and climate indicates both within WCPFC and to external stakeholders. We note the refinement of the indicator suite will be a 'living' project, open to change and amendment based on the evolution of WCPFC needs/applications.

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ANNEX I

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.

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