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Ecosystem and Climate Indicator Report Card from SC19

WCPFC-TCC19-2023-IP12[1]
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SPC-OFP

[1] This paper is Annex 2 to a paper that was posted to SC19 as SC19-2023-EB-WP01 *Ecosystem and Climate Indicators*

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.

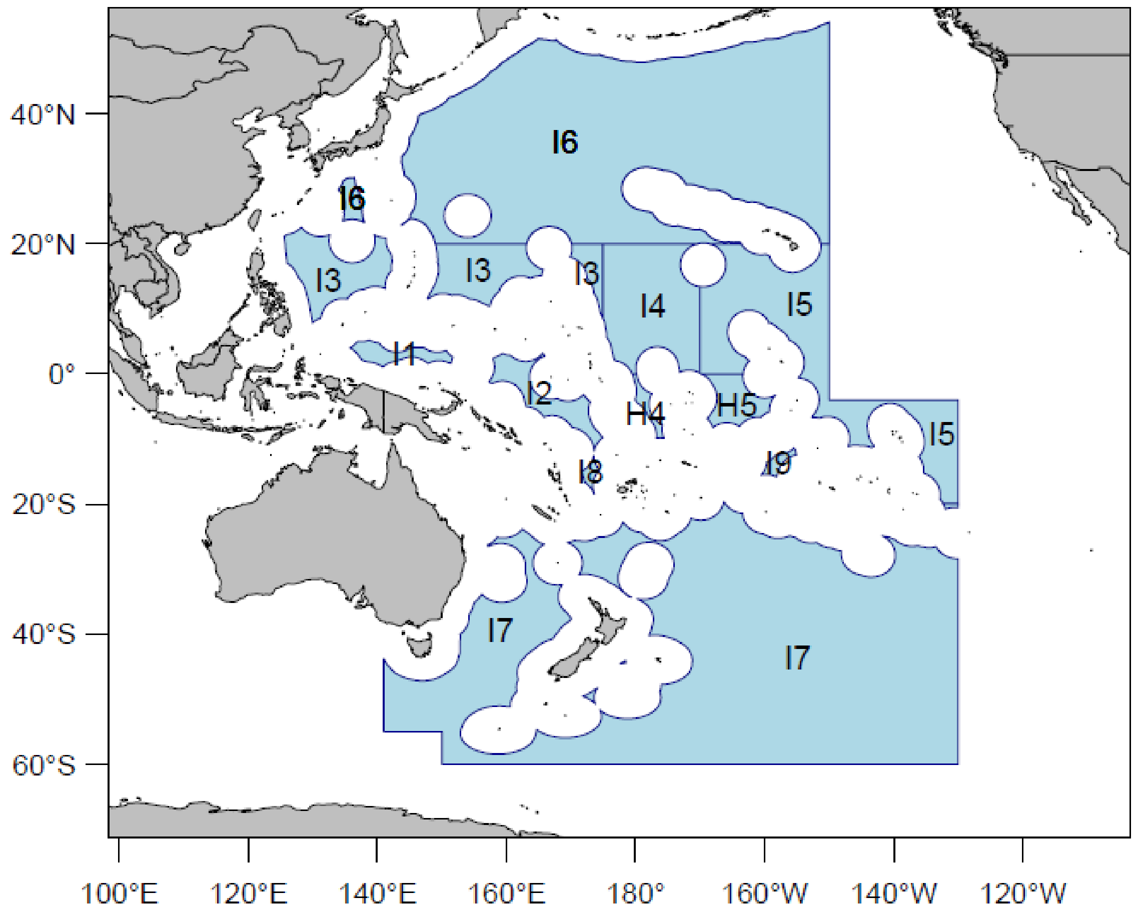
The central tendency of purse seine fishing effort was defined here by the 'centre of gravity', i.e. the mean location (latitude and longitude) of fishing effort. This was calculated by year for each fishing mode i.e. 'unassociated' free-school sets (UNA) versus 'associated' sets (ASS). We present only 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 $K_{\mathrm{rel}} = WW/aUF^b$ (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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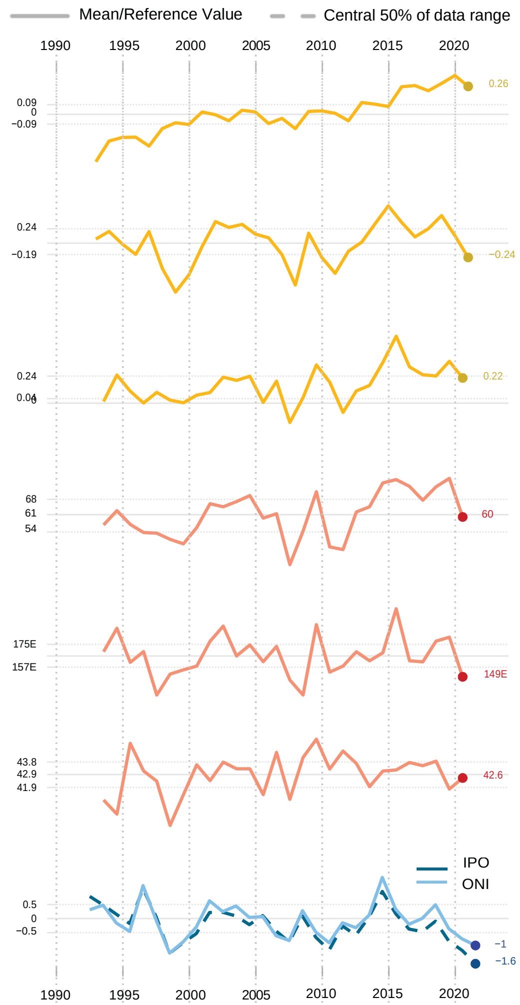
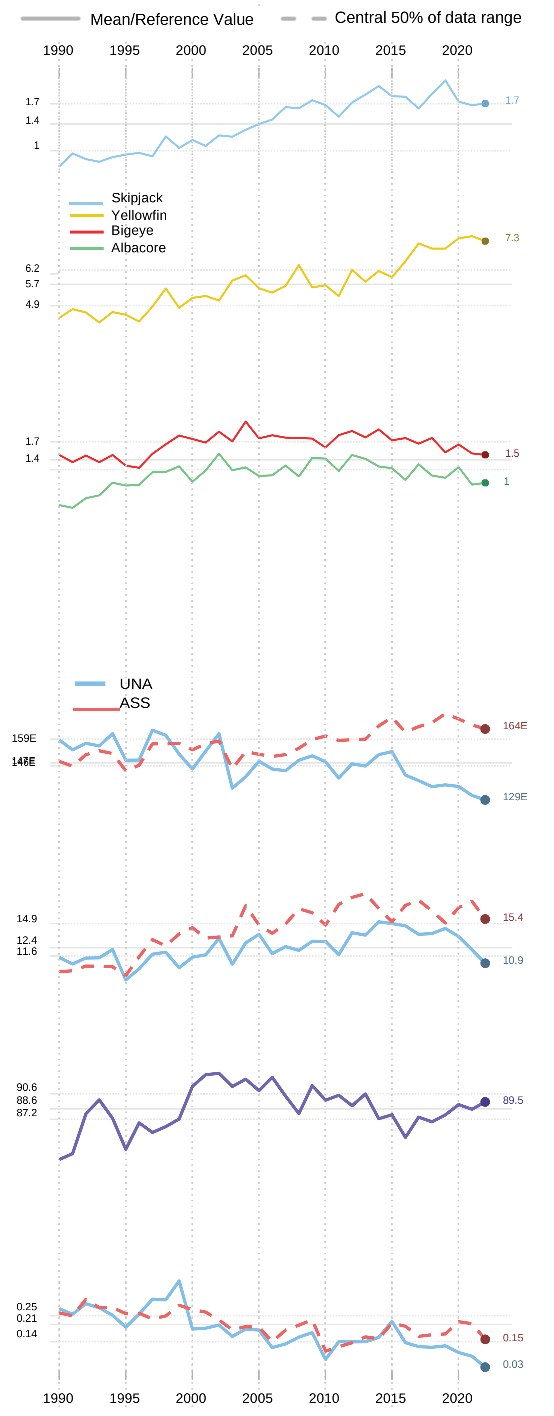
Indicator	Description	Notes
Sea Surface Temperature Anomalies (ANNEX 1 - A.1)		
Annual SST Anomaly	Mean annual SST anomaly (°C) across **WCPO area**	• Derived from ocean models • WCPO area western limit of 130°E • Anomaly from mean temperature 1993-2021
	Mean annual SST anomaly (°C) across **WCPO equatorial 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

Time-series



Report Card 2. Annual Tuna Catch & Fishing Effort Indicators

Indicator	Description	Notes	Time-series
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	



Report Card 3. Biology & Bycatch Indicators

Indicator	Description	Notes
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

Time-series