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Background analyses for the 2024 stock assessment of southwestern Pacific striped marlin

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1 Executive summary

This information paper provides details of the supplementary analyses and descriptions of information that support the 2024 assessment of southwest (SW) Pacific striped marlin. The paper focus on the CPUE analysis to produce the abundance index for the assessment and the treatment of the size composition data. Aspects of the biological inputs are also discussed and covered further in the stock assessment.

2 Background

To conduct the 2024 stock assessment of striped marlin (*Kajikia audax*) in the southwest Pacific Ocean it is necessary to develop a set of data inputs and external parameter inputs for the assessment. This is often a substantial amount of preparatory work that has to be completed prior to being able to run the new assessment models. This paper focus on providing information on the work done to develop the CPUE abundance indices and size composition data inputs.

The new assessment has a truncated start year compared to the previous assessments, starting in 1979 compared to 1954. While there were unresolved issues in the stock assessment estimation for early years in the catch history, 1979 was a logical later start point due to the availability of data on hooks between floats and vessel ID, plus a general low confidence in operational data for the key fleet taking striped marlin in the southwest Pacific prior to 1979 – Japan. The CPUE analysis was focused on this truncated model time period, and a combined fleets approach to utilize data from both the Japan and Chinese Taipei fleets to provide a better coverage of the model domain. The previous assessment focused on the Japanese fleet data, with separate indices for Chinese Taipei and Australian longline included as uncertainties.

We note that the spatial and fishery structural aspects of the assessments are consistent with the previous assessment and can found in the assessment paper (Castillo Jordan et al. 2024). In relation to this aspect of the assessment further support analysis can be found in Potts et al. (2024).

This paper also provides a set of plots in Appendices that summarise the available raw catch and size composition data available for each of the defined fisheries in the assessment.

The 2024 assessment is a single region areas-as-fleets model, there is no movement estimation required and no external data inputs such as tag-recapture data.

3 CPUE

3.1 Overview

Standardized CPUE indices are critical inputs to stock assessments conducted using integrated models (Fournier and Archibald, 1982). Based on the previously described fisheries definitions, standardized CPUE indices were constructed from catch and effort records for two of the major DWFNs operating in the model region: Japan and Chinese Taipei.

Both the Japanese and Chinese Taipei distant water longline fleets (JPDW & TWDW) have long histories operating in the Pacific region, and particularly in the assessment region for SW Pacific striped marlin. For Japanese longline fishing activity, aggregate monthly catch and effort data, provided at $5^\circ \times 5^\circ$ grid cells by the Japan Fisheries Agency were available for the assessment period. In addition, daily operational logbook catch and effort records were available at $1^\circ \times 1^\circ$ grid cells. The CPUE analysis for the 2024 assessment includes vessel ID, that started to be recorded by the Japanese in 1979. The desire to include vessel ID in the analysis was a factor behind the choice to start the model in 1979. Fishing by Chinese Taipei in the SW Pacific ocean provided another key source of information for the assessment. The development of their TW-DW fleet began in the 1960s, with operational logbook catch and effort records available from the Chinese Taipei Fisheries Agency at $1^\circ \times 1^\circ$ grid cells beginning in 1964, although the early operational data is of low confidence. These operational datasets are part of the larger Pacific-wide operational data set which was described by McKechnie et al. (2015). Chinese Taipei also has vessel ID available for the assessment period. To improve the spatio-temporal resolution of the CPUE, we combined both fleets during the assessment period from 1979 to 2022.

During the long period of both Japanese and Chinese Taipei fishing operations in the SW Pacific, systematic changes to fishing practices (change in number of hooks between floats, *HBF*), target species, and areas fished (Figure 1) occurred. These systematic changes manifest themselves on top of a background of gradual, persistent increase in vessel efficiency due to technological innovation or improved fisher knowledge. All of these may, independently or cumulatively, result in catchability changes and thus changes in the catch rates of striped marlin by these fleets. In order to account for these spatial and temporal changes in catchability, nominal CPUE data are typically standardized using a statistical model (Maunder and Punt, 2004).

The number of HBF is a commonly used variable in longline CPUE standardization as it is often assumed to be representative of the depth of the fishing gear. This assumption is based on the theoretical catenary geometry of a longline and that more HBF would add more weight to the line causing it to sink deeper. For a relatively shallow swimming species like striped marlin, this is an important covariate to consider as deeper longline sets may not be representatively sampling the population. HBF was available for the full period for the Japanese fleet. Chinese Taipei fleet started to register HBF in the mid-1990s. Similar to what was done previously (Hoyle et al., 2012), this analysis assumed that Chinese Taipei sets prior to 1995 had a gear configuration similar to that fished in the late-1990s (10 HBF).

4 Standardisation of catch and effort data

A spatiotemporal modeling approach was used to produce relative abundance indices for the index fisheries using the SW-Pacific operational longline data set. The longline data set extends back to 1952 and encompasses historical fishing information for distant-water fishing nations (DWFNs), Pacific island countries and territories (PICTs), and Australian and New Zealand (AU/NZ) fishing fleets. These data represent the most complete spatiotemporal record of longline fishing in the Pacific, and is a valuable product of a regional collaboration and data sharing initiative.

This data set was first compiled in 2015 to support the Pacific-wide bigeye tuna stock assessment (McKechnie et al., 2015), and has since been used to generate relative abundance indices and support the assessments of several tuna stocks in the region (McKechnie et al., 2017; Tremblay-Boyer et al., 2017, 2018; Ducharme-Barth et al., 2020; Teears et al., 2023). For the 2019 CPUE analyses, a spatiotemporal modeling approach for Southwestern Pacific striped marlin was implemented, using the VAST R package (Thorson et al., 2015). In 2024, the CPUE modelling approach builds upon these previous analyses, employing similar data filtering criteria and model structure, also noting the spatial domain for the 2019 and 2024 assessments are similar. The 2024 stock assessment used the sdmTMB geostatistical software package as was applied for the standardisation of CPUE data in 2023 for the bigeye and yellowfin tuna CPUE standardisation of longline data (Teears et al., 2023). The sdmTMB geostatistical software was selected as it has been developed to be computationally efficient, flexible, and user-friendly with online community support (Anderson et al., 2022) and thus, represents a reasonable alternative for improving reproducibility and efficiency of CPUE analyses.

Prior to undertaking the CPUE analysis, data (both the aggregated cell-month-HBF and the operational logbook) were filtered to match the protocol used in Hoyle et al. (2012). Data were removed if the number of hooks fished were ≤ 0, if no catches were reported, and if HBF were greater than 40 or missing after 1979. Data from trips pertaining to OS (offshore) vessels (both for Japan and Chinese Taipei) were also removed from the model in this analysis. The spatial patterns of nominal CPUE by flag and decade are shown in Figure 1.

Standardized CPUE indices were calculated at a year time step and include month as a covariate. CPUE was defined as catch of striped marlin in numbers per 100 hooks fished. A unique index for the region and separate indices were calculated for each of the 4 assessment sub-regions in the last assessment. In this case we conducted one geostatistical model for the entire model region.

4.1 Vessel identification (Vessel ID)

A CPUE standarization can consider categorical and continues covariates (Hoyle et al. 2024). In order to better account for changes in catchability, we incorporated Vessel ID as random effects in the 2024 striped marlin CPUE. Vessel ID can potentially capture effects arising from combinations of changes in vessel-specific characteristics such as fishing gear, vessel size/capacity, crew experiences and fishing behaviour, target species and fishing area. Vessel ID was available from 1979 to 2022, covering all the period of the assessment. The data coverage for vessel ID was close to 100% (0.9 percent of records did not have vessel ID).

4.2 Model configuration

Spatiotemporal models have been shown to be more accurate and less biased than equivalently structured delta-GLMs when fit to fisheries dependent data (Grüss et al., 2019; Zhou et al., 2019). Additionally, explicitly modeling the spatiotemporal structure of the data allows these models to cope with non-stationary effort distributions like the ones exhibited in the operational longline dataset (Ducharme-Barth et al., 2019b). As stated previously, a spatiotemporal model was developed using sdmTMB (Anderson et al., 2022) to model the longline data similarly to VAST. The sdmTMB software was selected for updating the CPUE analysis through 2022.

The models implemented in the sdmTMB package (version 0.3.0), were spatiotemporal delta generalized linear mixed models (GLMMs). These models accounted for an interactive relationship between space and time and were specified using Gaussian random fields to define the spatial and spatiotemporal components of the model. These Gaussian random fields are defined with a Matern covariance function. Using the estimated correlation structure of the data, spatiotemporal delta-GLMMs can simultaneously interpolate abundance of unobserved strata.

A delta-gamma configuration was used to standardise the CPUE data as it has been shown to provide optimal performance when the underlying error distribution is misspecified (Thorson, 2019). Specifically, the linear predictors for encounter probability and magnitude of positive catch rates (model component, encounter probability or positive catch rate) are modeled for knots and time step t, with the respective link functions (i.e.logit for the encounter probability and log link for the positive catch rates).

The delta-GLMM structure implemented in R using the sdmTMB package to update the CPUE analysis is defined as:

Binomial component[3]

$$y_i \sim Bernoulli(p_i)$$

$$log\frac{p_i}{1-p_i} \sim Year_i + \omega_1(s_i) + \phi_1(s,t_i) + s(HBF_i) + 1|VesselID_i + \varepsilon_1$$

[3]The version of sdmTMB (version 0.3.0) used in these analyses does not allow for covariates to be defined separately for each component of the delta model. Given that a continuous error distribution is used for the positive component and hooks fished is already included in the response variable, we were unable to use it as an offset in the binomial component of the model.

Positive component

$$c_i \sim \Gamma(log\mu_i, \sigma^-2, \eta_i\sigma^2)$$

$$log\eta_i \sim Year_i + \omega_2(s_i) + \phi_2(s_i, t_i) + s(HBF_i) + 1|VesselID_i + \varepsilon_2$$

where σ is the coefficient of variation of measurement errors for positive catch rates, y is the encounter probability, c is the CPUE, i is the record number, $Year$ is the year effect, ω is the spatial random effect at location x, ϕ is the spatiotemporal random effect at location x and time t, $s(HBF)$ is the spline on HBF, and $VesselID$ is the random effect of the vessels. The spatial variation terms $\omega_2(x_i)$ are assumed to come from a Gaussian random field, and treated as random effects, assuming a Matern covariance matrix to account for spatial autocorrelation.

$$\omega_m \sim MVN(0, \sigma_{\omega m}\mathbf{R_m})$$

The spatio-temporal random effects $\varepsilon(s_i, t)$ account for the interaction between time and the model spatial structure. Each model component has an observation level random effect ε, assumed to come from a Gaussian distribution with a mean of 0.

The spatial knot configuration (i.e., mesh parameterisation) was structured to include 144 knots (Figure 2). The extrapolation grid was at a 5°x5° spatial resolution across the spatial domain.

Predicted CPUE at each knot in each time period $d(s, t)$ was estimated by obtaining the product of the back-transformed linear predictors with catchability covariates (i.e., HBF and Vessel ID) held constant to remove their effects on estimates of relative abundance.

$$I(t) = \sum_{s=1}^{N_s} a(s)d(s, t)$$

where $a(s)$ is the area associated with knot s. Region index and sub-Region indices were calculated as the area in each region associated with each knot, multiplied by the respective CPUE; standard errors associated with the indices are calculated internally in Template Model Builder (TMB) using the inverse Hessian and the delta method (Anderson et al., 2022). We only focus on results for the full region as this was what was used in the assessment.

We included the residuals analysis from sdmTMB package (Anderson et al., 2022) know as PIT (probability-integral-transform) residuals.

4.3 Results

4.3.1 Catch and effort summary maps

For the description of the average CPUE maps (Figure 1), we focus mainly on the flags included in the CPUE analysis (Japan and Chinese Taipei), and for the time period of the analysis. The average CPUE by flag group shows the predominance of the Japanese fleet in the 70s and 80s Pacific wide. In the 90s the average CPUE for Japan shows more focused values near the coast of Australia and in the eastern Pacific, in equatorial waters. In the 2000s and 2010s the average CPUE for the Japanese fleet decreases considerable compared with the previous decades, with patchy average CPUE in the same areas as in the 90s. For Chinese Taipei, the other fleet included in the CPUE analysis, there is a consistent pattern with similar area covered in the 70s and 80s. In the 90s, the Chinese Taipei fleet contracts to the western side of the Pacific, with similar average CPUE to the 80s. In the 2000s, this fleet expands spatially, but without much change to the average CPUE. In the 2010s, the patterns are similar to the previous decade, but covering a slightly smaller area.

4.3.2 Model diagnostics

The model used for the CPUE analysis passes all standard diagnostic tests included in sdmTMB (sanity checks), such as successful convergence, positive definite hessian matrix, and low gradients ($< 10^{-3}$). In addition the PIT residuals analysis is normally distributed (Figure 3). The map of residuals does not show any strong patterns, indicating that the residuals are distributed randomly in the study area (Figure 4).

4.3.3 Model components

The encounter probabilities (Figure 5) in the Southwestern Pacific ocean varied (seasonally) at $\sim$ 8-15% throughout the time series. The full period shows a decadal fluctuation represented in the smoother of the encounter probability component of the model, with the last few years coinciding with the ascending part of this cycle. On the other hand, the positive component of the standardization model, also shows an indication of seasonal variation (Figure 6). In the study area, the positive component shows roughly decadal trends, declining slowly, from 1979 until 1990, then a decade of relative stability until 2000, followed by a decline until 2010, followed by general stability through to the end of the time series. The last few years indicate a possible small increase, which will need to be confirmed with additional data and future analysis.

4.3.4 Standardized CPUE and nominal CPUE

The nominal and the standardized CPUE differ from each other at the beginning and end of the series. The increase in the number of hooks in the nominal CPUE does not reflect what is shown with the standardized CPUE. However both CPUE series follow a similar trend until early 2000s. In the last 15 years of the time series, the difference increases between nominal and standardized

CPUE, with the standardized CPUE higher and with more fluctuation than the nominal CPUE (Figures 8 and 9).

5 Biology

After the 2019 assessment there was a review of some of the biological inputs to that assessment as there was a recognition that there may be some issues or biases in those inputs due to methodological flaws, in particular with regards to the growth model and maturity at length ogive. Farley et al. (2021) aimed to address some of those concerns, and recognised there were issues with both the growth and maturity ogives for southwestern Pacific striped marlin used in the previous assessment. The key outcomes from Farley et al. (2021) were discussed at the Pre-assessment workshop (Hamer, 2024) where the lead author clearly recommended updates to the growth and maturity ogives based on the reanalysis.

5.1 New Growth

The new growth model applied in the 2024 assessment is substantially different to that applied in the diagnostic case model in the 2019 assessment (Figure 10). The most notable difference is the substantially higher K parameter. This has the effect of reducing the age at which fish become vulnerable to the fishery, which can potentially have significant implications for how the population responds to fishing pressure. Due the higher K, the size at L_1 (which is the size of the first model age class = 1 year) is notably larger in the new growth model.

A comparison of the growth parameters used in the current and previous assessments follows, with all length parameters expressed in terms of eye-orbital fork length (EFL):

- **2024** assessment: L_1 142.84 cm, L_∞ 208.06 cm, and K 0.83658
- **2019** assessment: L_1 121.03 cm, L_∞ 220.53 cm, and K 0.44941

5.2 New maturity ogive

Two changes have implication for the 2024 maturity ogive. MFCL takes a maturity-at-length ogive as input and converts this internally to a maturity-at-age ogive. The maturity-at-length ogive was updated based on Farley et al. (2021) who reanalysed all the histology samples used from the previous ogive (Kopf et al., 2012) to confirm the interpretation methods. The maturity status of only three of the 150 females classified differed between the two datasets. However, differences were detected in the shape of the maturity ogive, which was primarily due to the different classification of one female as immature in the current study and mature in Kopf et al. (2012). The new maturity ogive further differed from the previous assessment due to the data in Kopf et al. (2012) being binned into 15 cm length classes (the new ogive is based on 5 cm bins) prior to model fitting, and also a different regression relationship being used.

Farley et al. (2021) recommend the use of the maturity ogive from the revised analysis (Figure 11) for future assessments of striped marlin in the WCPO until new ovary samples can be collected and included in the analysis. We note there are few new ovary sample data to update an ogive, and negligible new biological samples overall, despite recommendations from Farley et al. (2021) and the previous assessment (Ducharme-Barth et al., 2019a) to increase sampling efforts to improve growth and maturity analyses.

The maturity-at-age ogive calculated internally in MCFL applies the new growth and this also results in substantial changes to this ogive, with fish maturing at younger ages resulting in an increased proportion of younger fish being included in spawning biomass calculations.

5.3 Update length-weight relationship

The a and b parameters of the length-weight relationship were revised based on a direct length (EFL) and weight data. This involved data from Kopf et al. (2012) for n = 114 coupled length and weight records that were measured (directly as EFL) on striped marlin captured in NZ and Australian waters between 2005 and 2008. The update parameters are:

- **2024** $a = 5.399420 \times 10^{-7}$, $b = 3.583776$
- **2019** $a = 4.498996 \times 10^{-7}$, $b = 3.616484$

5.4 Steepness and natural mortality assumed prior distributions

Natural mortality: The new assessment aimed to improve on the approach to characterising uncertainty in management quantities by implementing a Monte Carlo ensemble approached based on drawing values from prior assumed distributions for the steepness parameter of the stock recruitment relationship and the $\bar{M}$ used in the Lorenzen M at age formulation in the assessment (Ducharme-Barth and Vincent, 2021; Neubauer et al., 2023). The prior $\bar{M}$ was based on the Hamel and Cope (2022) $A_{\max}$ method with, with A_{max} assumed to be 15 yr based on the oldest fish aged using otoliths. Hamel and Cope (2022) recommended a CV of 0.31 for $\bar{M}$. However, we found that sampling from this distribution produced a significant number of low (< 0.25) and high (> 0.7) values of $\bar{M}$ that were considered outside the likely range. Therefore, the CV was reduced to 0.2 to focus the replicates on a more plausible range of $\sim 0.25 - 0.55$. The $\bar{M}$ drawn from the prior were converted to Lorenzen M-at-age matching the prior M to the average of ages 2-10 years (age at 50% maturity age of plus group). For the diagnostic model $\bar{M}$ of 0.36 yr^{-1} was specified using the $A_{\max}$ approach assuming an $A_{\max}$ of 15 years. This compares to a value of 0.4 used in the 2019 assessment. The assumed prior for $\bar{M}$ is shown in Figure 12.

Steepness: We initially explored using the approach of Brodziak (2012) for generating a steepness prior, as was done for south Pacific albacore. Our conclusion was that, on balance, it was better to modify the prior for steepness so that high values > 0.99 and low values < 0.5 had much lower probability than as indicated in the distribution. The approach that we therefore adopted was similar to one used by (Ducharme-Barth and Vincent, 2021), and in the south Pacific albacore assessment. This recognised that the application of Jon Brodziak's approach using life-history criteria was indicating that steepness on average was likely to be considerably higher than what had been assumed in previous assessments. Secondly, we also wanted to respect the previous thinking, including meta-analyses, that indicated a reasonable range of steepness was likely to be around 0.65–0.95, which had led to the previous SC approach in the factorial grid. We therefore ultimately landed on using the prior shown in Figure 13 that takes these considerations into account.

6 Reweighting of size composition data

This section describes the reweighting of size composition data prior to integration into the assessment model. Statistical correction of size composition data is required as length samples are often collected unevenly in space and time such that the samples require reweighting using either catch, to be representative of the size of fish being removed from the population in the case of extraction fisheries, or estimates of relative abundance, to be representative of the size of fish in the population in the case of index fisheries. The reweighting procedure was applied to size compositions of longline fisheries.

6.1 Methods

The procedure used to reweight the size compositions was based on that used to prepare size compositions for the 2023 bigeye and yellowfin assessments (Peatman et al., 2023).

6.1.1 Data preparation

Length data for striped marlin have been provided to SPC based on four different length measurement methods: eye orbit-fork length (EFL), lower jaw-fork length (LJFL), bill tip-fork length (BFL) or pelvic fin-fork length (PFFL). A range of weights were supplied including whole weight, Japanese processed weights (gilled, gutted, head and tail left on, bill removed at a point level with the tip of the lower jaw), and gilled, gutted and headed (i.e. trunked) weights. All length measurements were standardized to EFL and weight measurements were standardized to the equivalent whole (unprocessed) weight using the conversion factors listed in Williams and Smith (2018).

Exploratory analyses of the length data identified apparent contamination of 1cm length frequency data by 5 cm length classes. In cases where the original length measurements were EFL, the contamination by 5 cm length classes appears as ‘spikes’ (i.e., over-representation) of 1cm length classes at regular 5 cm intervals. In cases where the original length measurements were not EFL, the contamination by 5 cm length classes appears as spikes at irregularly spaced intervals, depending on the mapping of 1cm length classes in the original unit of measurement to 1cm length classes in EFL equivalents.

Binomial tests were applied to the LF Master dataset, in order to identify and address 1cm data with apparent contamination by 5 cm length classes. For a given strata, we tested for 5 cm length class contamination by calculating the number of samples in 1cm length classes that are multiples of 5, and then applying a (one-tailed) binomial test for greater than expected numbers for length classes that were multiples of 5 cm. The expected probability was conservatively set to 0.3. A p-value of 0.1 was considered appropriate for the threshold for identification of contaminated data. Length data identified as contaminated was then converted to 5 cm length classes to allow appropriate treatment when preparing compositional inputs, e.g., excluded when preparing compositions with the 6 cm interval length classes used in the previous assessment (Ducharme-Barth et al., 2019a).

Contamination with 5 cm length classes was relatively rare, with 3% of total length samples from affected strata, though strong when present (Figure 14).

Length classes with 6 cm intervals were used in the 2019 assessment (Ducharme-Barth et al., 2019a). However this precludes the use of length data originally submitted to SPC with 5 cm length classes. For this assessment, 5 cm length intervals were considered preferrable, to allow both 1cm and 5 cm length interval data to inform size composition inputs. Data submissions with 5 cm intervals represent 23% of the total samples in LF Master, and 75% and 100% of length samples from the 'Japanese longline size data' (origin ID JPLL) and 'Taiwanese longline size data' (origin ID TWLL) datasets. As such, the 5 cm interval data has the potential to better inform the assessment, particularly in the context of the index fisheries in this assessment, which only use data from longliners flagged to Japan and Taiwan (see Section 5.4). However, we note that both 5 cm and 6 cm length class intervals are impacted by non-EFL data submissions contaminated with 5 cm length classes in the original unit of measurement.

Length compositions were prepared with 6 cm length classes used in the 2019 assessment (i.e., 52 length classes covering the range 20 to 332cm with lower limits 20cm, 26 cm, . . . , 326 cm), and 63 5 cm length classes covering the range 20 to 335 cm (with lower limits 20cm, 25 cm, . . . , 330cm). Weight compositions were prepared with the 2kg intervals used in the 2019 assessment covering the range 5 to 251kg, with lower limits 5kg, 7kg, . . . , 249kg.

6.2 Reweighting of size compositions

Striped marlin length and weight samples from longline fisheries were extracted from SPC's LF Master and WT Master databases, along with aggregate longline catch data from SPC's A BEST database. Striped marlin size samples and aggregate catch data were matched, and aggregated, to consistent flag-fleet groupings using lookup tables provided by SPC's Data Management team. The size samples and aggregate catch data were then aggregated to a year-quarter temporal resolution to match the structure of the assessment model.

The reweighting procedure was implemented at a 10 x 20° spatial resolution. However, 10 x 20° cells can span multiple assessment regions, as well as the boundary of the spatial domain of the assessment model. As an initial step, size samples were aggregated to a 10 x 20° and region spatial resolution as follows:

1. All size samples were split to a 5° spatial resolution using the proportion of reported catches of striped marlin (numbers) by 5° degree cell for a given year-quarter and flag-fleet. For example, size samples provided at a 10 x 20° resolution would be split between a maximum of eight 5° cells.

2. The 5° cells were then assigned to an assessment model region, and any 5° cells outside the spatial domain of the assessment model were excluded.

3. The size samples in each region were then aggregated back up to a 10 x 20° and region spatial resolution, i.e. an overall resolution of year-quarter, region, 10 x 20° cell and flag-fleet.

The size compositions for extraction fisheries were then reweighted separately for each size metric (i.e., length or weight) using the following approach:

1. For a given fishery, size samples and aggregate catches (numbers) were aggregated to a strata resolution, with strata defined by year-quarter, 10 x 20° cell and fishery, i.e., spatial stratification.

2. The size samples were filtered for strata with a minimum number of samples, to attempt to reduce noise in size compositions due to low sample sizes.

3. 'Strata weights' were then calculated using the proportion of catch over a time-window of $2k+1$ quarters accounted for by each 10 x 20° cell

$$W_{i,t} = \frac{\sum_{\tau=t-k}^{t+k} C_{i,\tau}}{\sum_i \sum_{\tau=t-k}^{t+k} C_{i,\tau}}$$

   where $W_{i,t}$ and $C_{i,t}$ are the strata weight and catch (respectively) for 10 x 20° cell i and year-quarter t.

4. Strata-level numbers by size class were then converted to proportions by size class.

5. Strata-level proportions by size class were then weighted by multiplying by the appropriate strata weight $W_{i,t}$.

6. The weighted proportions by size class were then summed across strata to obtain proportions by size class and year-quarter for the fishery.

7. The fishery-resolution proportions by size class were then raised to numbers by size class, by multiplying by the total number of size samples for the fishery and year-quarter.

8. The MFCL fishery resolution size compositions were then filtered for year-quarters where sampled strata accounted for a minimum proportion of striped marlin catch, i.e., filtering for year-quarters where the sum of strata weights from sampled 10 x 20° cells exceeded a specified threshold. This limit is referred to as the 'minimum sampled weighting'.

9. The reweighted size compositions were then summed across quarters to provide annual size compositions, to match the temporal resolution of the assessment model.

The reweighting procedure for index fisheries was equivalent to that used for extraction fisheries, though with the following exceptions. Strata weights and minimum sampled weightings for index fisheries were based on the proportion of estimated relative abundance from the CPUE standardisation models by 10 x 20° cell, rather than catch. Additionally, the temporal resolution of strata for index fisheries was year rather than year-quarter, to match both the temporal resolution of estimated relative abundance from the CPUE standardisation models and the structure of the assessment model. Year-quarter was kept as the temporal resolution of strata for extraction fisheries, which enables variation in spatial distributions of catches or sampling intensity among quarters to be accounted for when reweighting compositional inputs.

Spatial stratification was used to reweight length compositions for both extraction and index fisheries, i.e. strata for a given fishery were defined as combinations of 10 x 20° cell and time-steps. A time window of 11 quarters ($k = 0$) was used for extraction fisheries, with k set to 0 for index fisheries. A minimum sampled weighting of 0 was applied for both extraction and index fishery compositions. A minimum of 30 samples per strata was implemented for weight compositions, with a lower threshold of 10 samples per strata implemented for length compositions. The strength of filtering is relatively low compared to those typically used in other stocks assessments in the WCPO, to prevent excessive filtering of compositional data due to the comparatively limited sample sizes for striped marlin.

6.3 Input sample sizes for the assessment model

We refer to the unit of frequencies of the reweighted size compositions as the ‘input sample size’. The reweighting procedure implicitly scales the input sample size for a given fishery and time-step by the proportion of catch (extraction fisheries) or relative abundance (index fisheries) from sampled strata (i.e., sampled 10 x 20° cells). For example, if sampled 10 x 20° cells accounted for 75% of the total catch for an extraction fishery in a given time-step, then the input sample size would be equal to 75% of the original sample size for that time-step.

Input sample sizes were also further reduced by 50% for fisheries where samples were used for both extraction and index fishery size compositions. We note that the input sample sizes are typically further decreased within MFCL as part of the model fitting procedure.

6.4 Index fisheries

Size compositions for index fisheries were prepared using all length and weight samples from Japanese and Taiwanese longliners, to match the subset of fleets used when fitting the CPUE standardisation models. However we note that all weight samples were collected on Japanese vessels.

6.5 Results and discussion

In the 2019 assessment, size compositions for striped marlin were not reweighted. The reweighting of size compositions provides a number of advantages. In this assessment, index fisheries were separated from extraction fisheries, and the reweighting procedure ensures that the compositional inputs are weighted appropriately to reflect changes in the underlying population structure (index fisheries) and catches (extraction fisheries). Additionally, the reweighting procedure includes data filtering steps that can reduce noise in compositional inputs and remove artefacts caused by limited or unrepresentative sampling (e.g., Figure 15).

Reweighted length compositions for extraction fisheries are provided in Figures 16-26, with weight compositions for extraction fisheries provided in Figures 27-32. Index fishery compositions are provided in Figure 33 and Figure 34 for lengths and weights, respectively. Appreciable levels of apparent noise remained in reweighted size compositions, particularly in years with comparatively low sample sizes (e.g., Figures 23, 31). However, there were indications of cohort progression for a number of fisheries (e.g., Figures 16, 24).

Spatial stratification was used to reweight compositions for both index and extraction fisheries. This accounts for spatial variation in size compositions within the area covered by a fishery but does not account for any additional variation between flag-fleets. Ideally, stratification both spatially and by flag-fleet should be used for extraction fisheries, to account for both of these potential sources of variation. However, there was insufficient sampling coverage to implement more detailed stratification in the reweighting procedure for all extraction fisheries, noting that moving to a finer stratification increases the risk of introducing additional noise into time series of size compositions.

Statistical tests were used to identify apparent contamination of 1cm length frequencies with 5 cm length classes. This approach provides an objective framework to address the issue of contamination with larger length intervals, but a degree of subjectivity remains, e.g., in the selection of appropriate p-value thresholds. Additionally, the tests may return false positives for cases with relatively high frequencies of a single (or relatively few) length classes, particularly when the sampled fish cover a limited range of lengths. The binomial tests used here were able to identify length data with apparent contamination. However, further investigation of contamination of 1cm length data with length classes of longer intervals is recommended for striped marlin, as well as the other tuna and tuna-like species covered by the LF Master dataset. Potential avenues of exploration include testing of alternative thresholds and expected proportions applied with the binomial test approach currently implemented, as well as trialling of alternative approaches. It may also be possible to address the issue of contamination directly at the data source, particularly in more recent years where Members may be more likely to have the raw data. Regardless, the issue reiterates the importance of size data submissions having the correct information on the associated interval of the size classes. There was also suggestions of contamination of 1kg weight frequency data (e.g., Figure 34). Statistical tests applied to the WT Master dataset did not detect this apparent issue, which may reflect contamination with irregularly spaced weight classes which are more difficult to test.

Additionally, specifically for striped marlin, there is the unresolved issue of addressing contamination of 1cm length data with longer interval length classes in the original unit of measurement, where lengths were not measured in eye orbit – fork length. This raises additional problems, as 5 cm length classes in the original unit of measurement can't be directly mapped to 5 cm length classes in eye orbit – fork length equivalents. Mean preserving splines could be used to split the (non-EFL)

5 cm data to finer resolutions (e.g., 1cm length classes or smaller) to facilitate conversion of 5 cm non-EFL data to 5 cm EFL data (Rymes and Myers, 2001).

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8 Figures

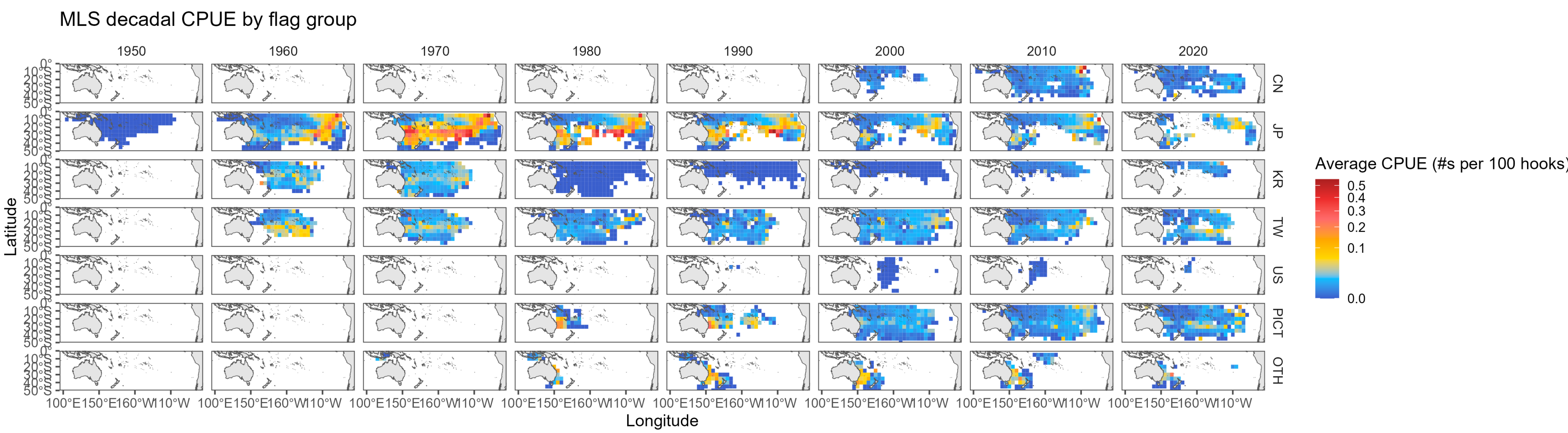


Figure 1: Spatial patterns of Nominal CPUE by decade and flag.

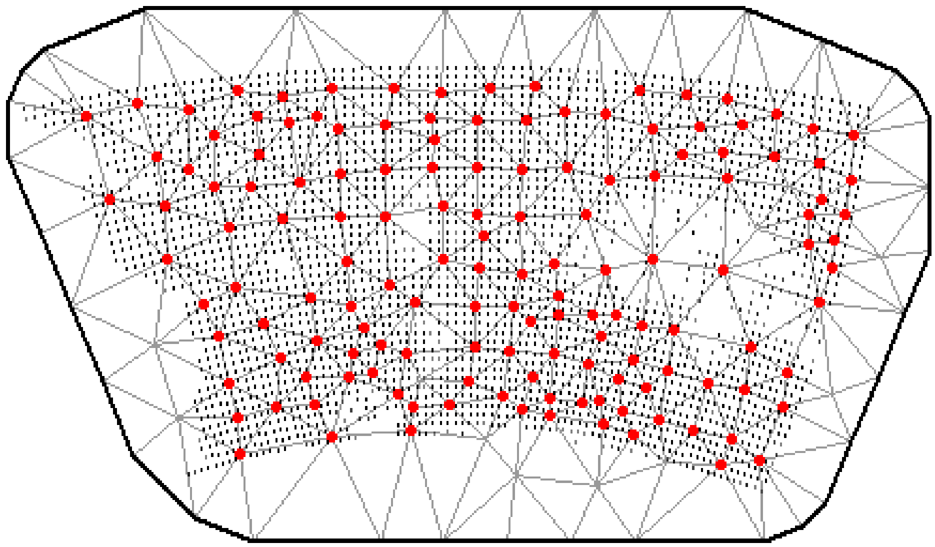


Figure 2: Spatial mesh knot structure used for the sdmTMB geostats model. The colored dots indicate locations of spatial observations within the $5^{\circ} \times 5^{\circ}$ grid shown in white.

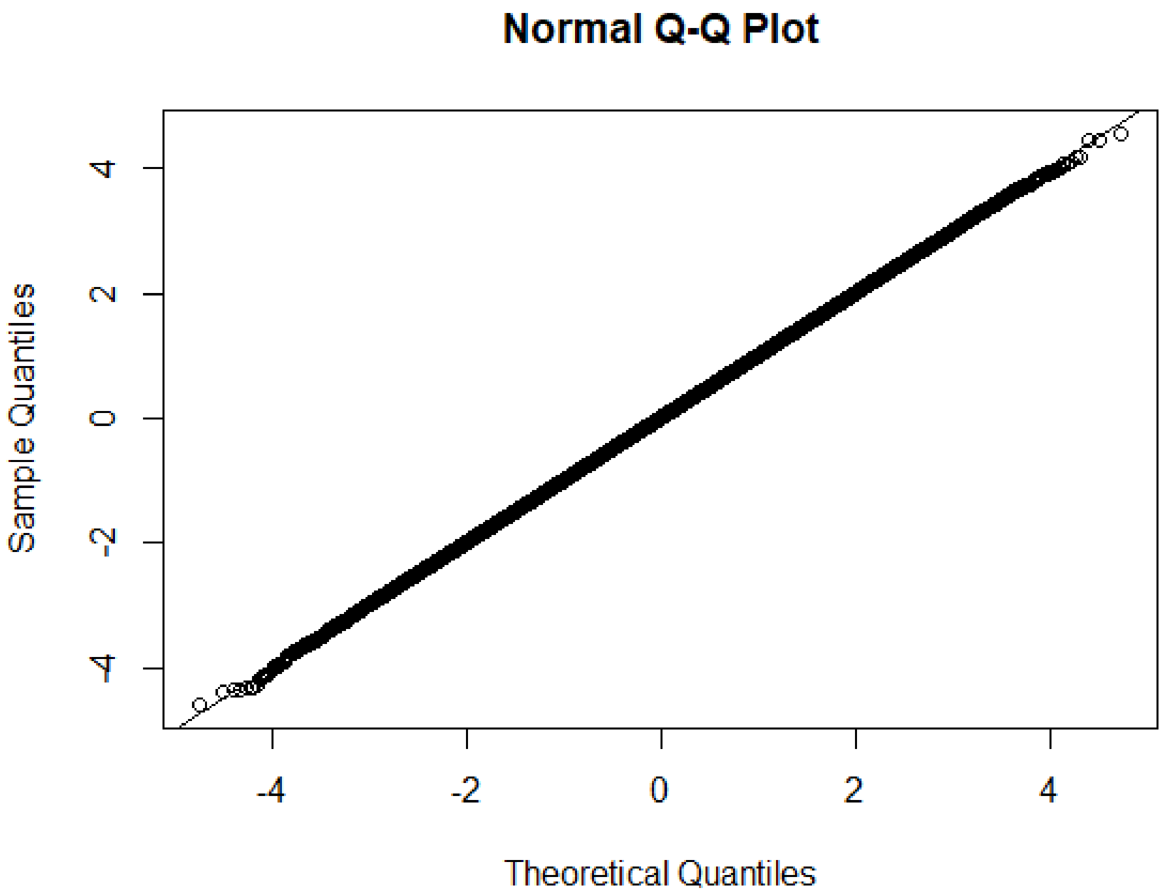


Figure 3: Normal QQ plot for the distribution of residuals

Figure 4: Spatial distribution of probability-integrated-transform (PIT) residuals aggregated across the full time series for striped marlin standardised CPUE at the level of the 5° grid cell

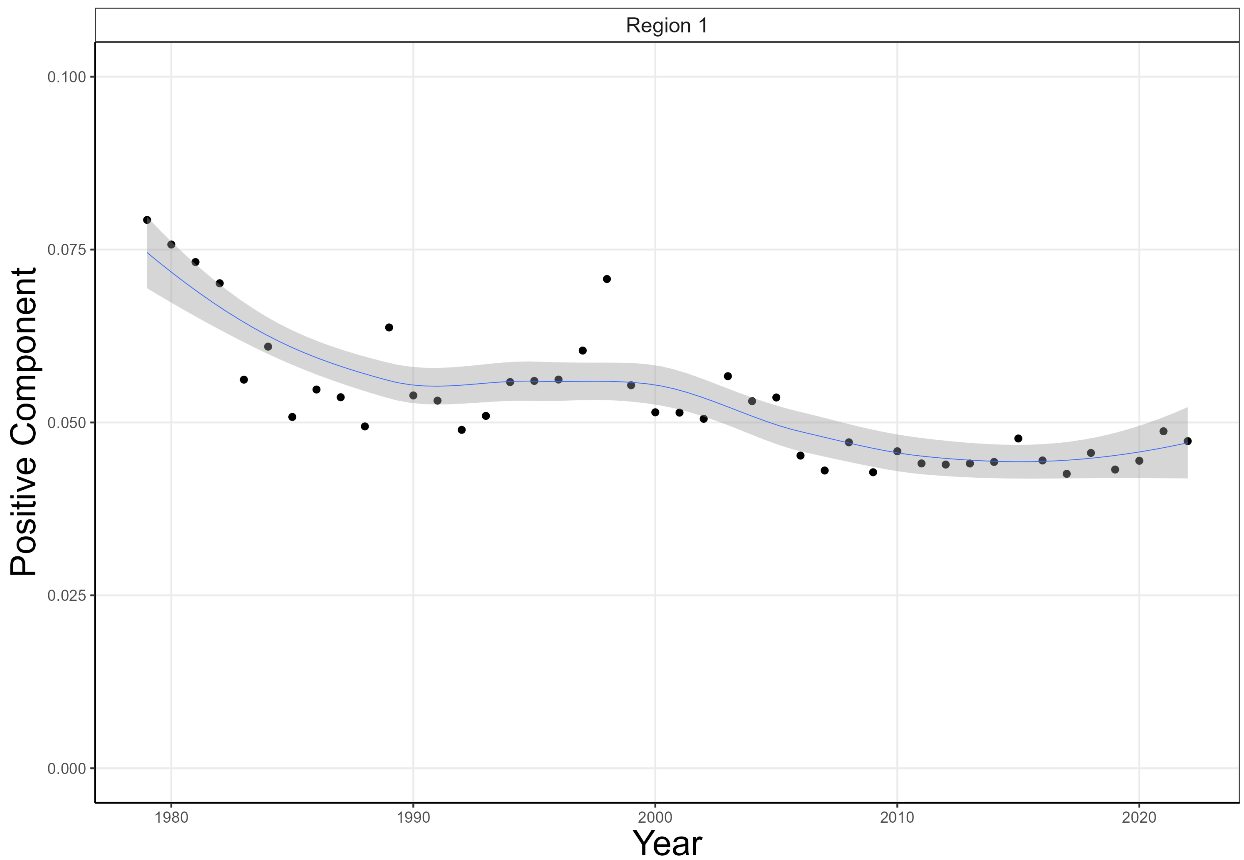


Figure 5: Time-series of positive model component by with loess smooth line (blue) with standard error (grey shading).

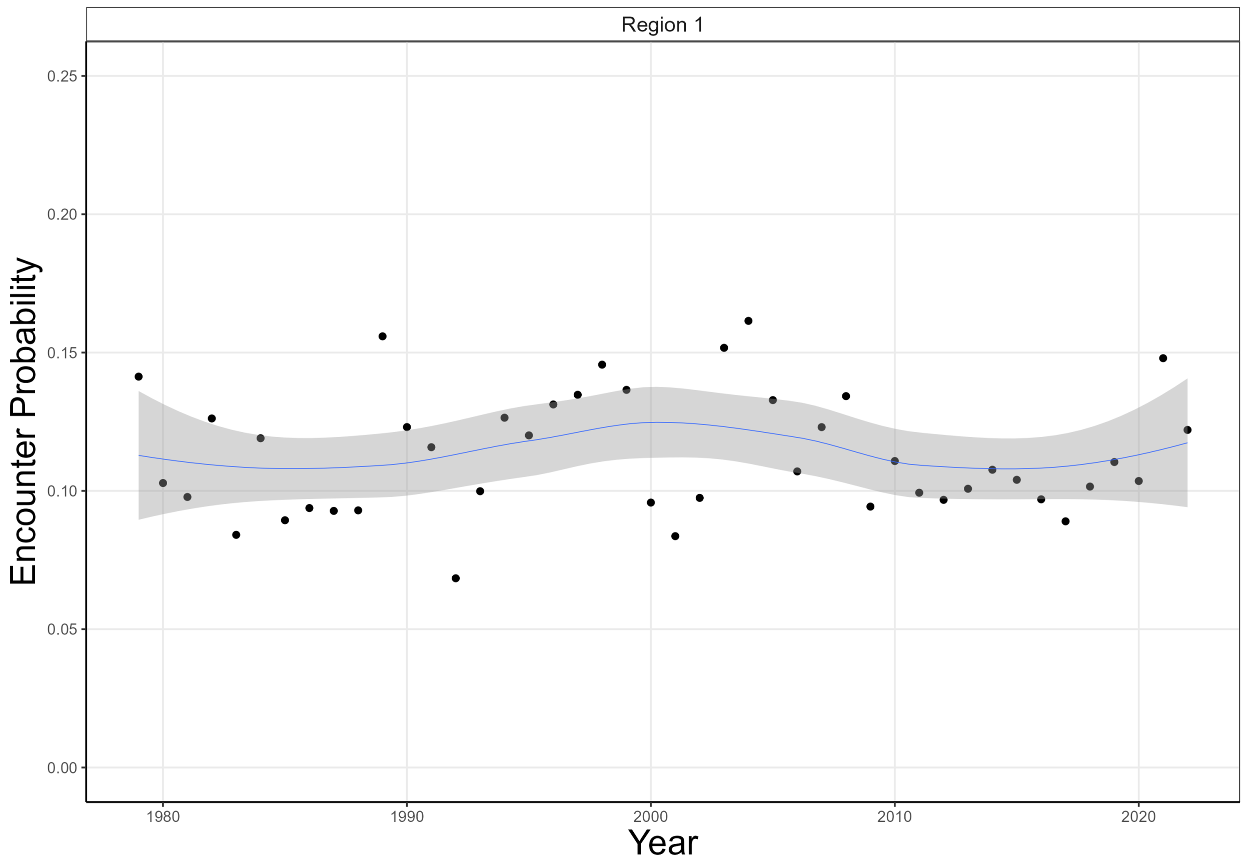


Figure 6: Time-series of encounter probability with loess smooth line (blue) with standard error (grey shading).

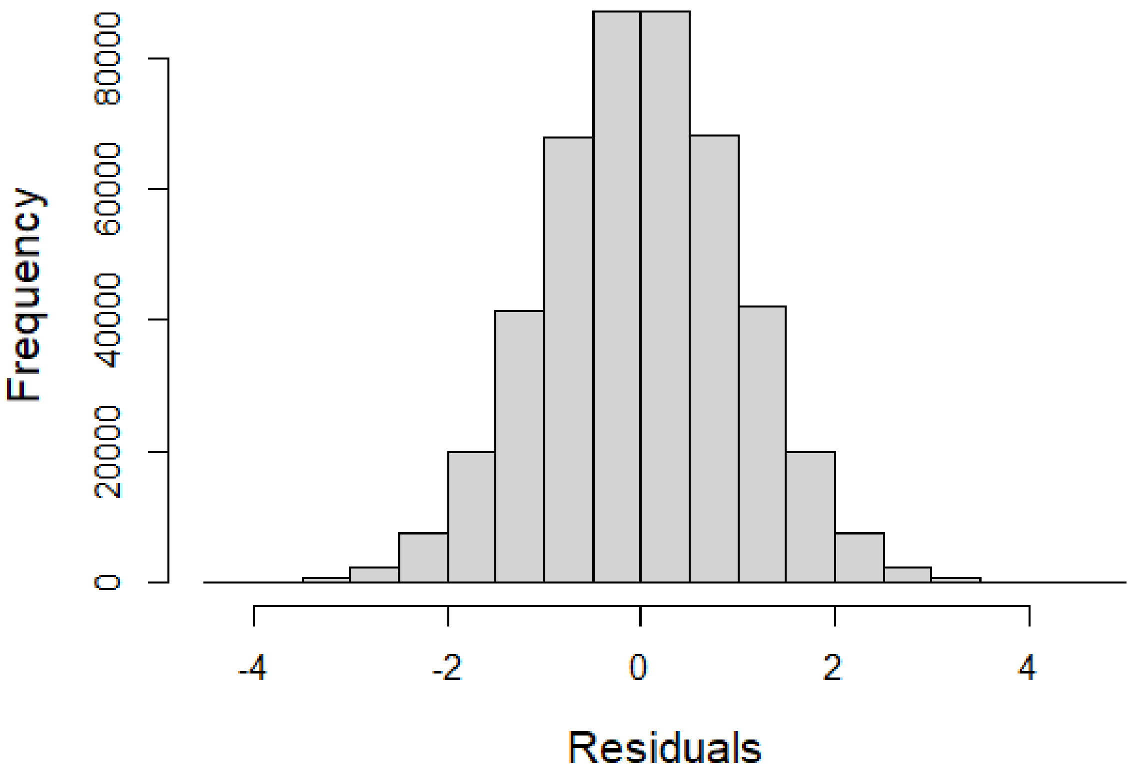


Figure 7: Histogram of aggregated PIT residuals

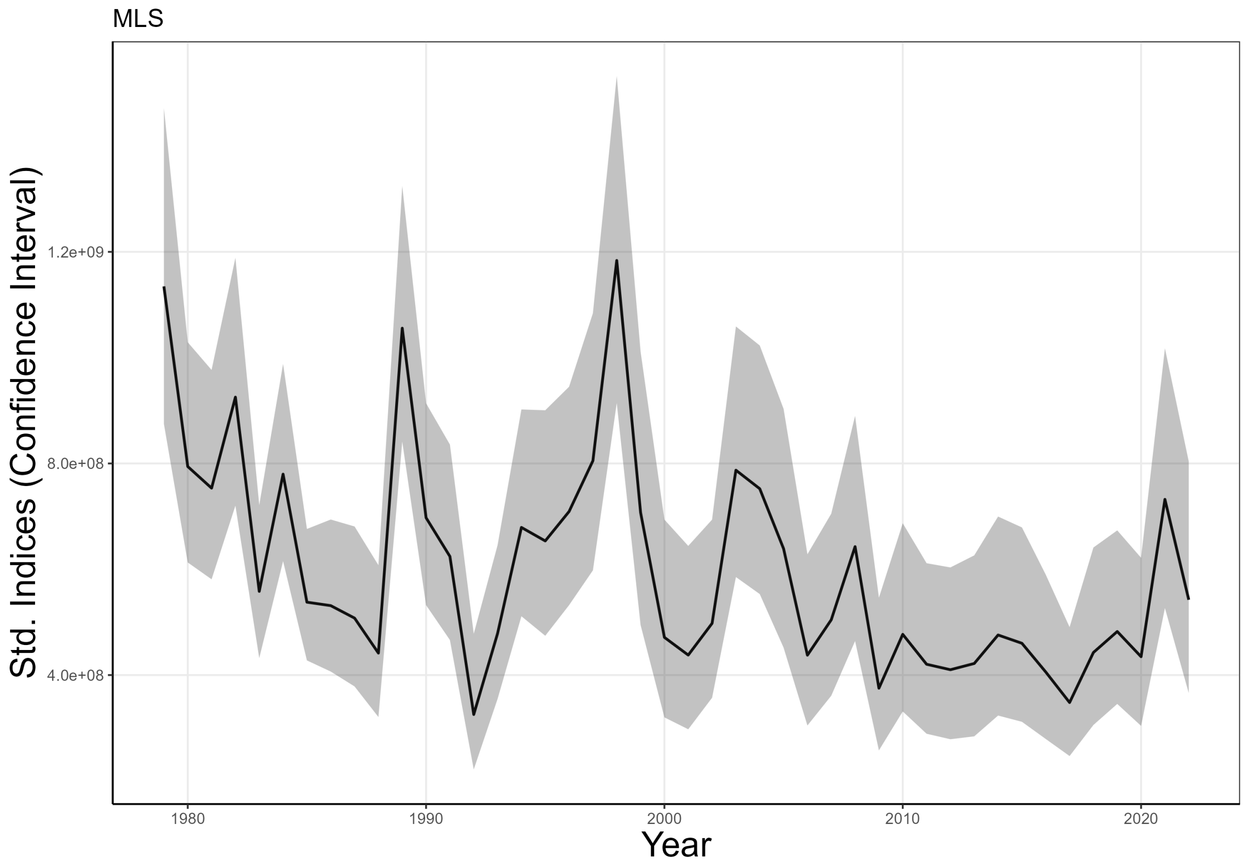


Figure 8: Standardized CPUE index estimated from the combined JPDW/TWDW data across the model region, with 95% confidence interval.

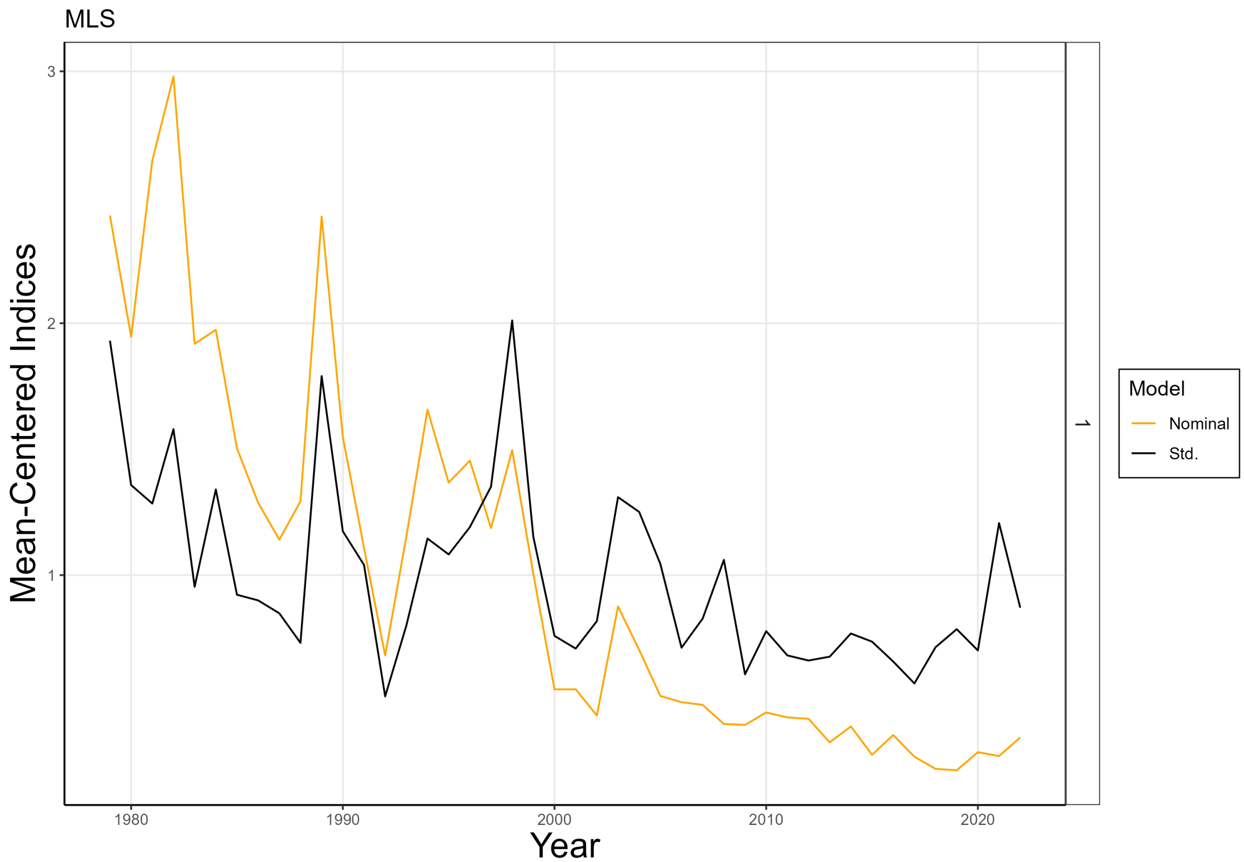


Figure 9: Nominal (yellow) and Standardized (black) CPUE indices estimated from JPDW/TWDW across the model region.

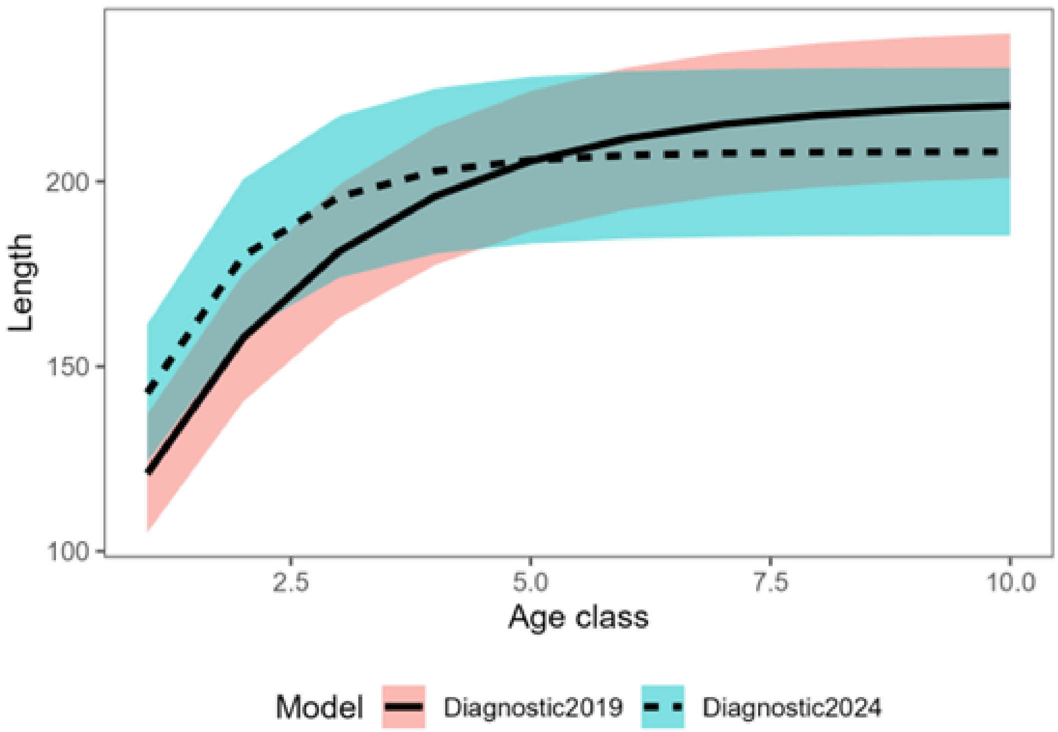


Figure 10: Growth comparison for the 2019 and 2024 diagnostic model. The growth used in the diagnostic model 2019 (Kopf et al., 2011) is shown in red and the growth function used for the diagnostic model 2024 developed by CSIRO using otolith aging is shown in green. The estimated uncertainty in growth shown as ±1 standard deviations from the mean.

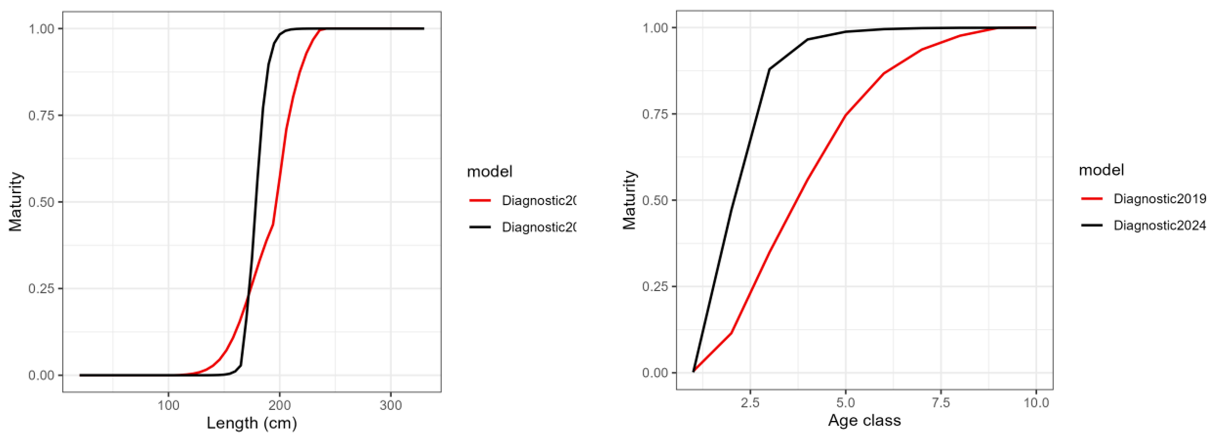


Figure 11: Comparisons of maturity ogives at length (left) and age (right) for the 2019 and 2024 diagnostic models.

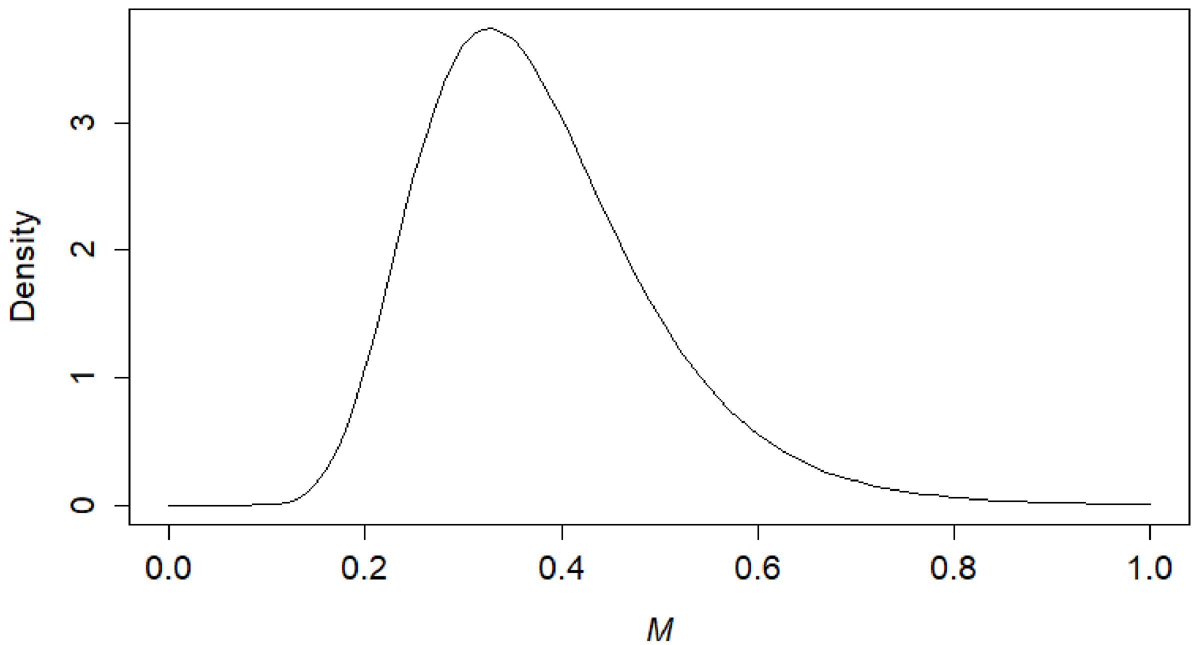


Figure 12: Assumed prior distribution for average natural mortality ($\bar{M}$).

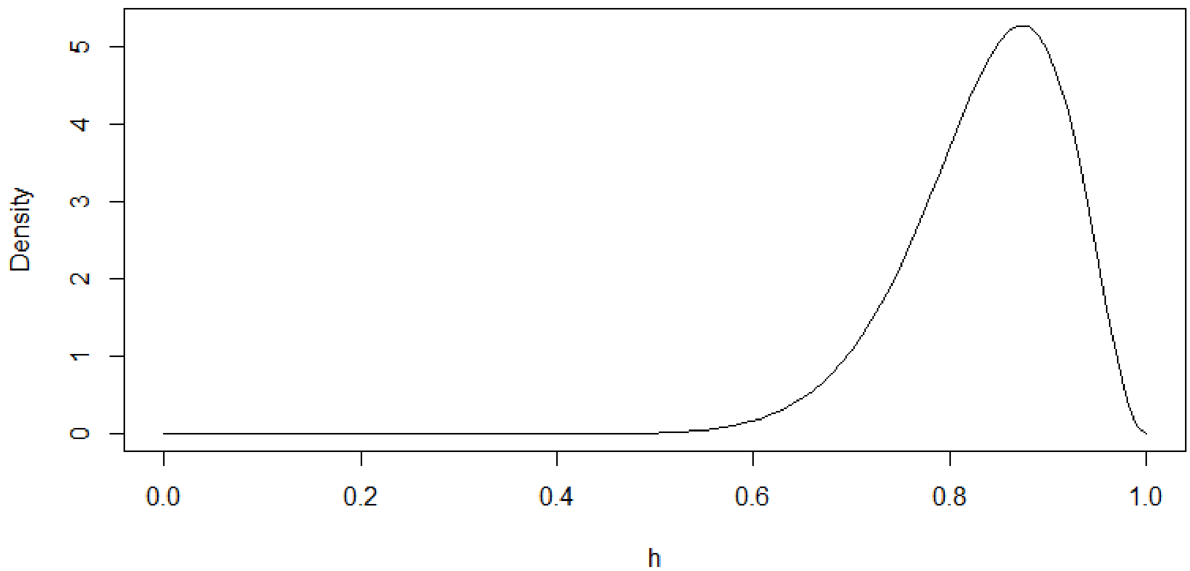


Figure 13: Assumed prior distribution for steepness (h).

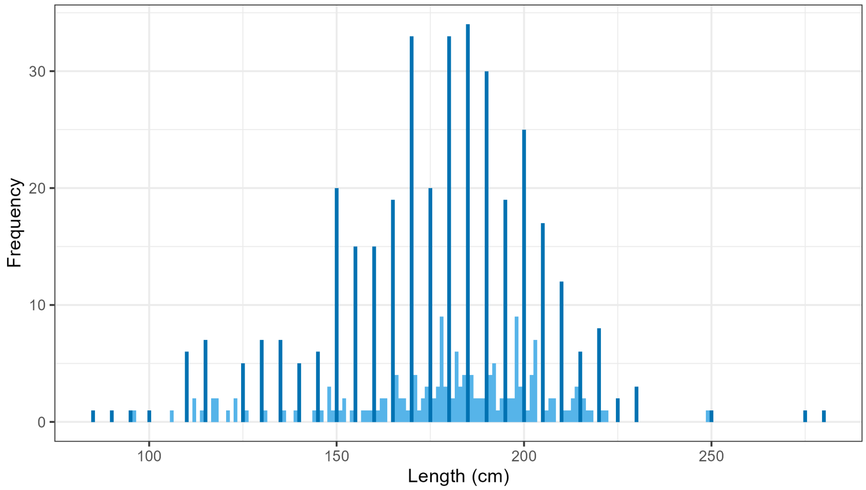
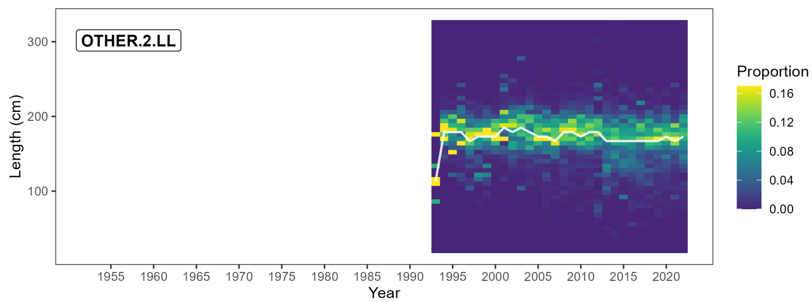
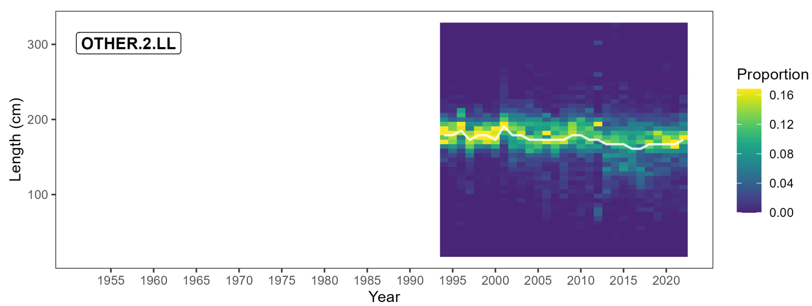


Figure 14: Overall striped marlin length frequency from LF Master strata that were identified as contaminated with 5cm length classes (e.g., $150 \leq$ length < 155 cm), based on binomial tests. 1 cm length classes that are multiples of 5 are dark blue, with other length classes light blue.

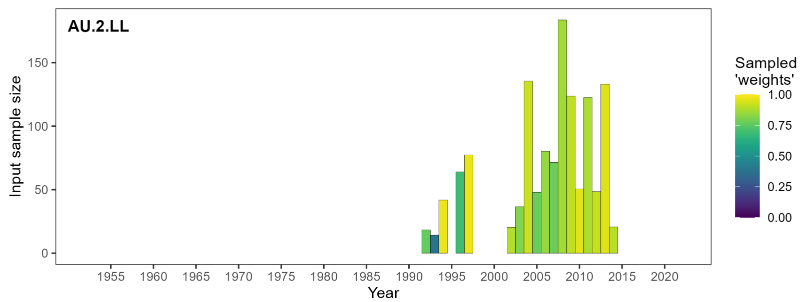


(a) Unweighted size compositions with no data filtering

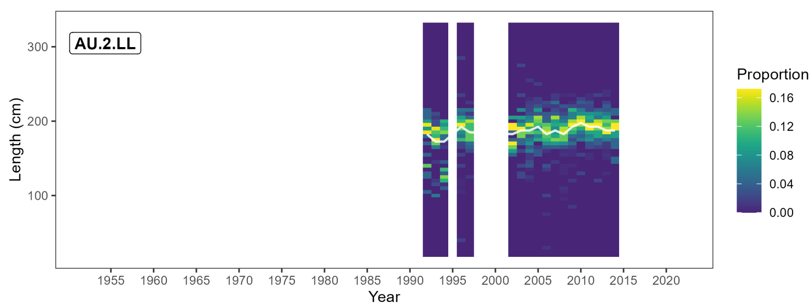


(b) Reweighted size compositions with data filtering

Figure 15: a) Unweighted length compositions with no data filtering, and b) weighted length compositions when including data from strata with a minimum of 10 samples, for the 'other' longline extraction fishery in subregion 2 and 6cm length classes from the 2019 assessment (Ducharme-Barth et al., 2019a)

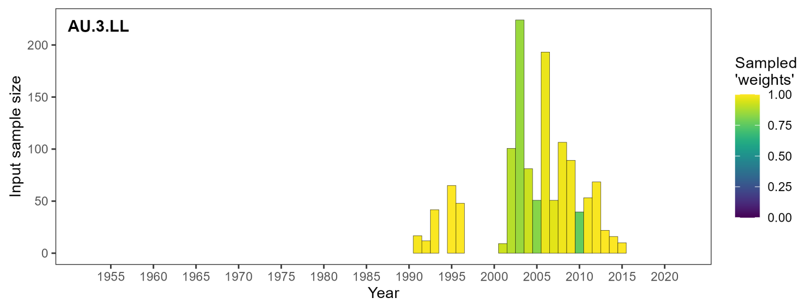


(a) Input sample sizes of length compositions

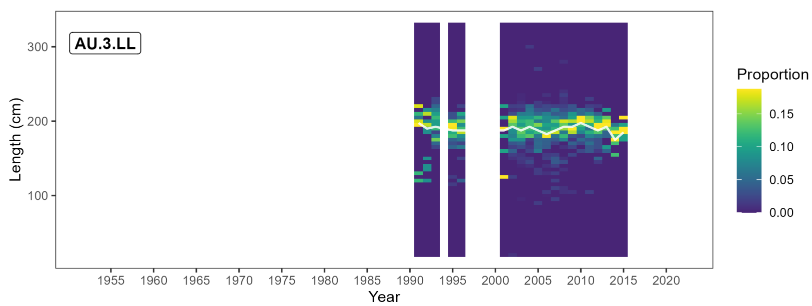


(b) Reweighted length compositions

Figure 16: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the AU extraction longline fishery in subregion 2.

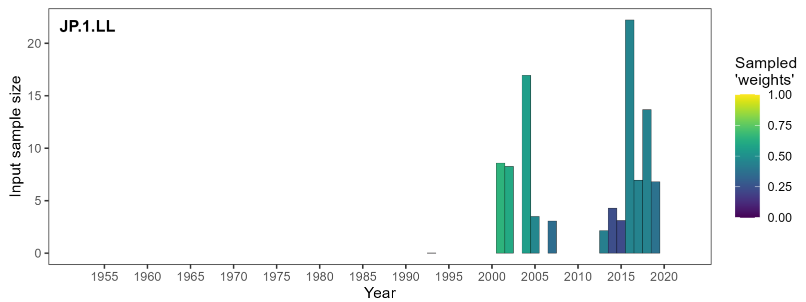


(a) Input sample sizes of length compositions

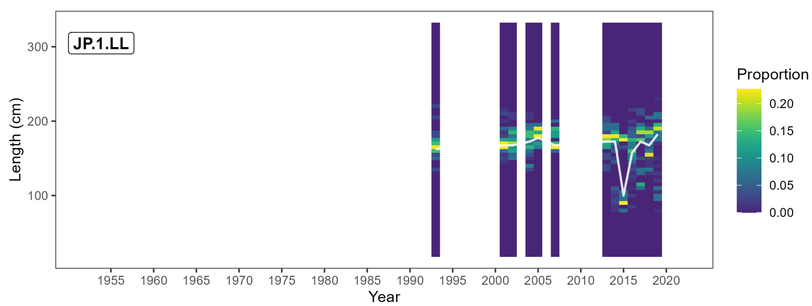


(b) Reweighted length compositions

Figure 17: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the AU extraction longline fishery in subregion 3.

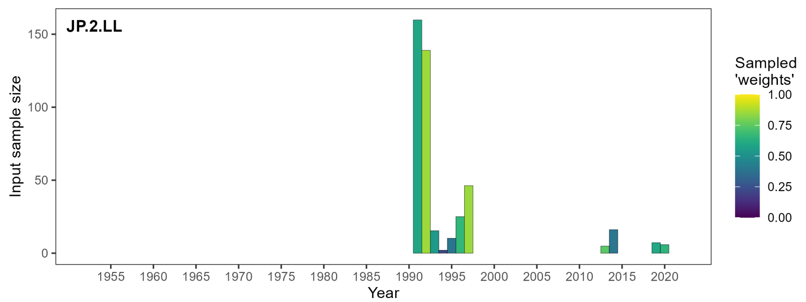


(a) Input sample sizes of length compositions

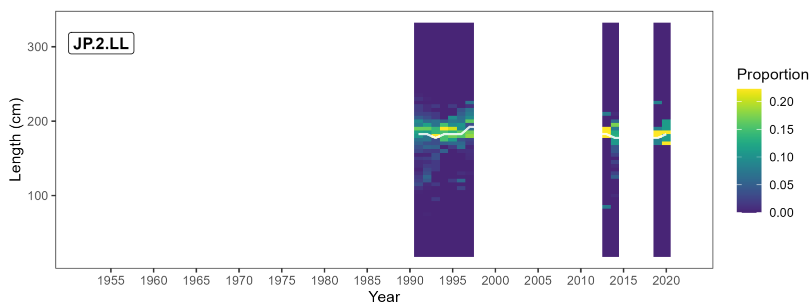


(b) Reweighted length compositions

Figure 18: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the JP extraction longline fishery in subregion 1.

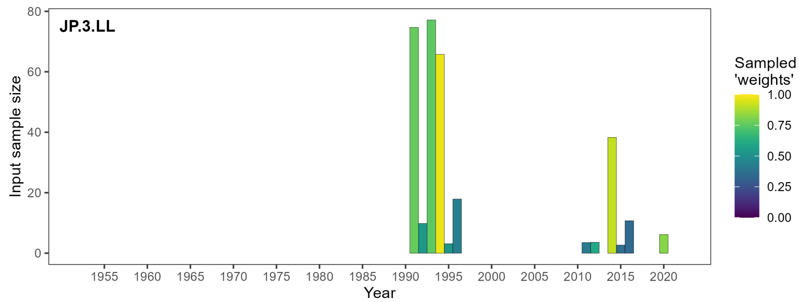


(a) Input sample sizes of length compositions

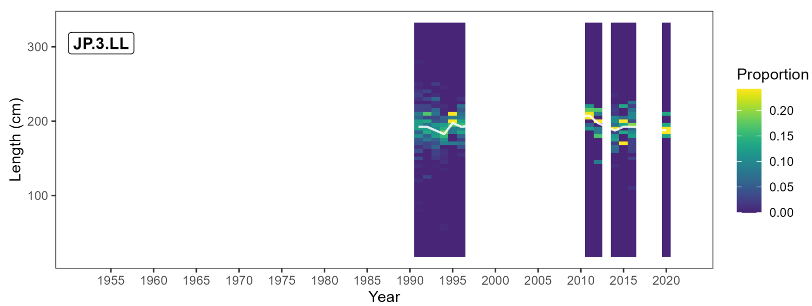


(b) Reweighted length compositions

Figure 19: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the JP extraction longline fishery in subregion 2.

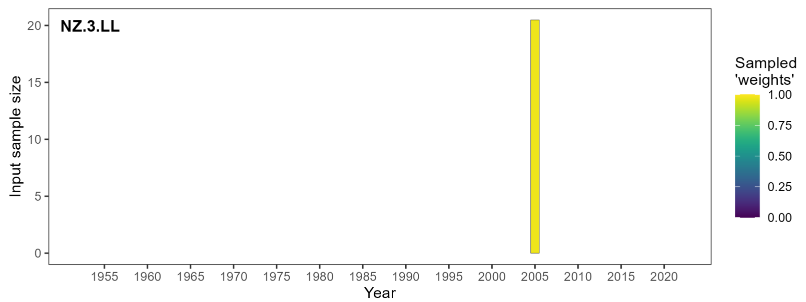


(a) Input sample sizes of length compositions

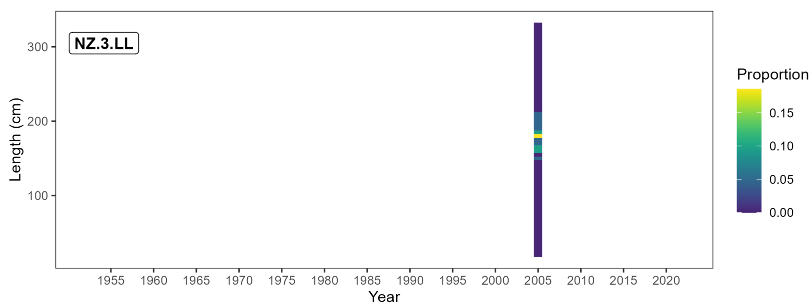


(b) Reweighted length compositions

Figure 20: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the JP extraction longline fishery in subregion 3.

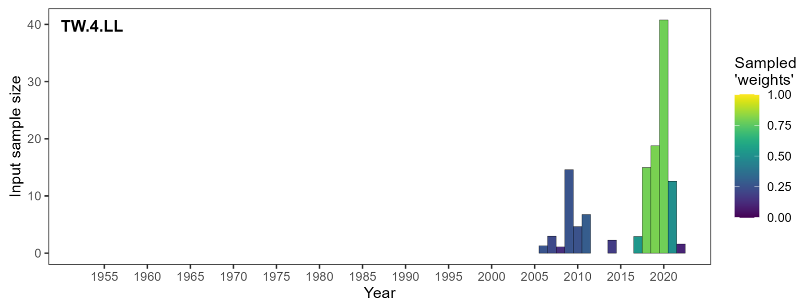


(a) Input sample sizes of length compositions

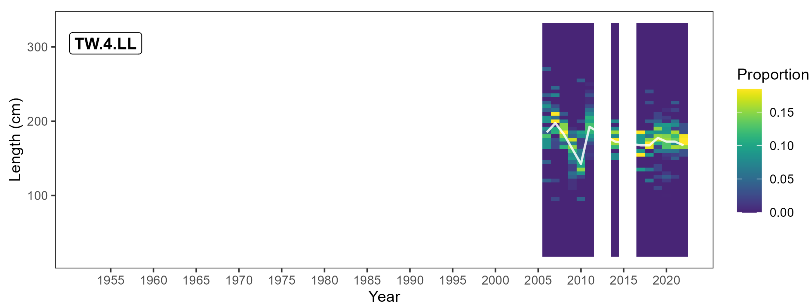


(b) Reweighted length compositions

Figure 21: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the NZ extraction longline fishery in subregion 3.

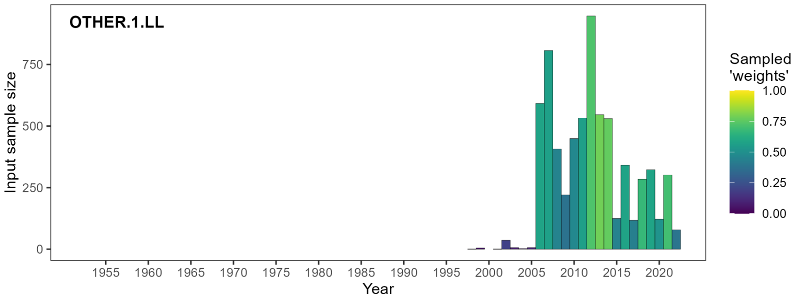


(a) Input sample sizes of length compositions

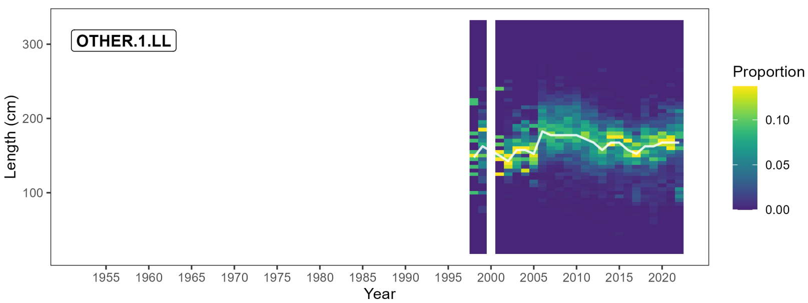


(b) Reweighted length compositions

Figure 22: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the TW extraction longline fishery in subregion 4.

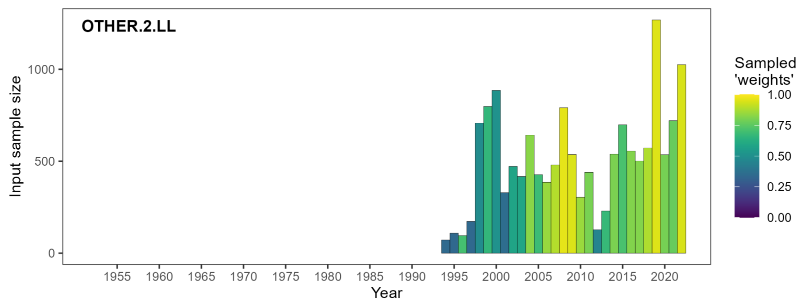


(a) Input sample sizes of length compositions

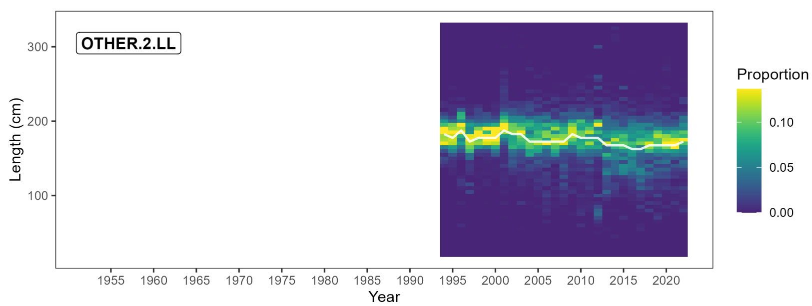


(b) Reweighted length compositions

Figure 23: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the 'other' extraction longline fishery in subregion 1.

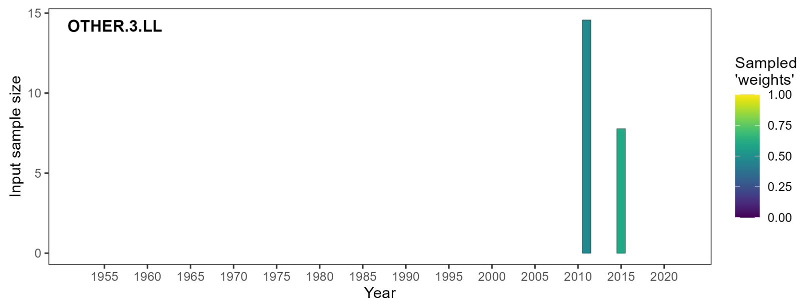


(a) Input sample sizes of length compositions

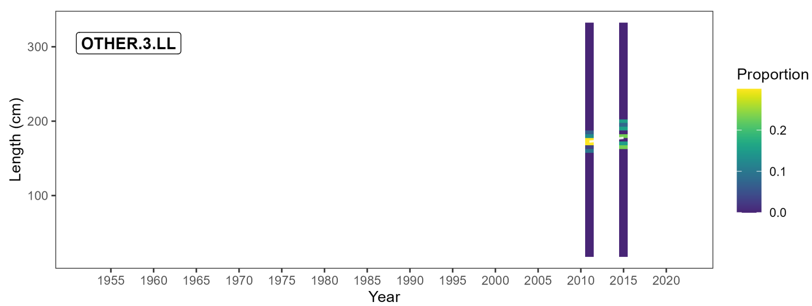


(b) Reweighted length compositions

Figure 24: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the 'other' extraction longline fishery in subregion 2.

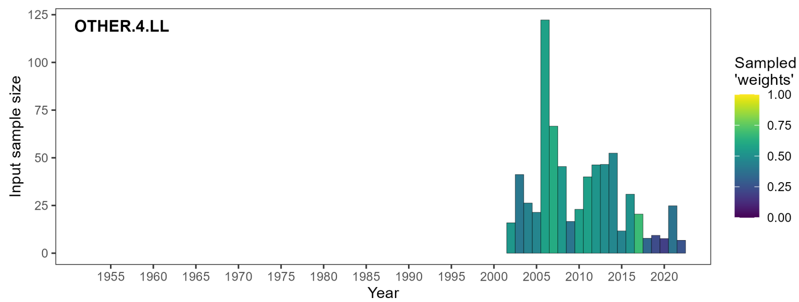


(a) Input sample sizes of length compositions

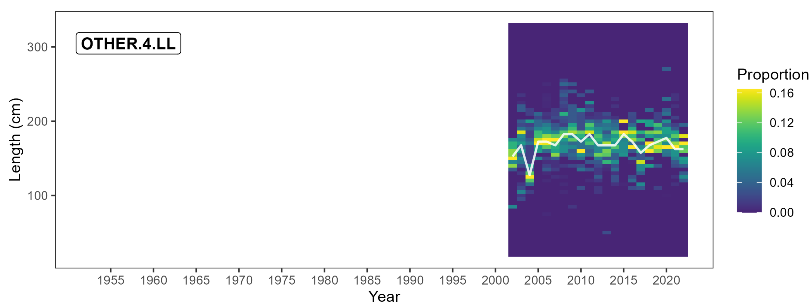


(b) Reweighted length compositions

Figure 25: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the 'other' extraction longline fishery in subregion 3.



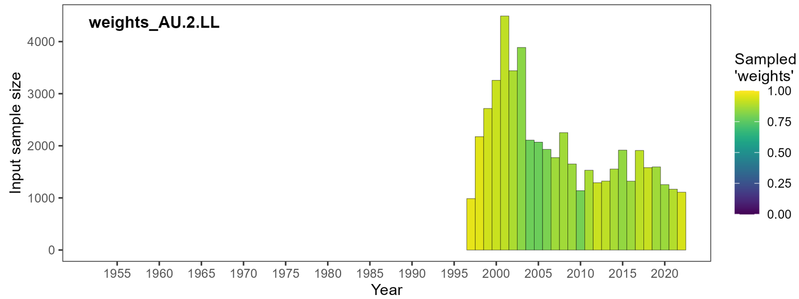
(a) Input sample sizes of length compositions



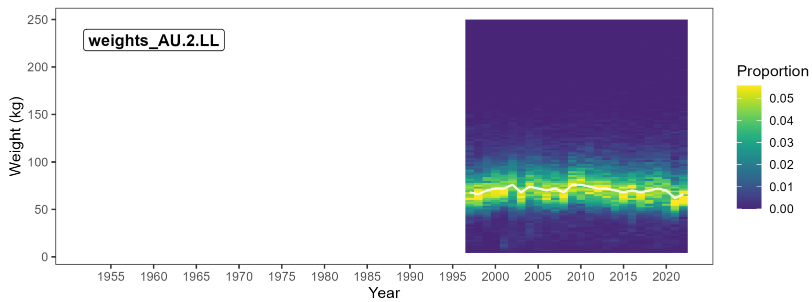
(b) Reweighted length compositions

Figure 26: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the 'other' extraction longline fishery in subregion 4.

8.1 Extraction fisheries - weight compositions

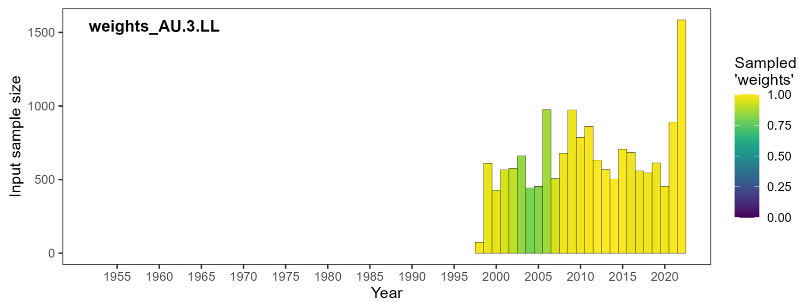


(a) Input sample sizes of weight compositions

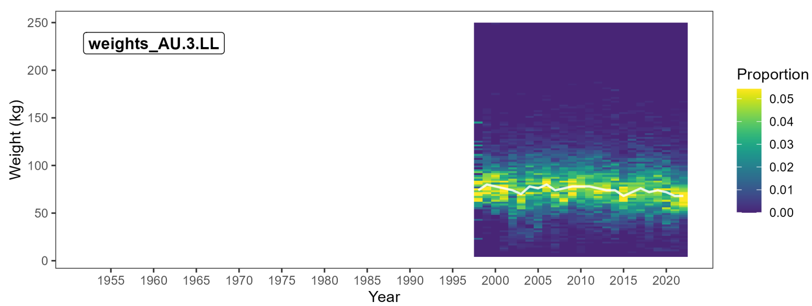


(b) Reweighted weight compositions

Figure 27: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted weight compositions with 2kg weight classes (white line provides the median weight class), for the AU extraction longline fishery in subregion 2.

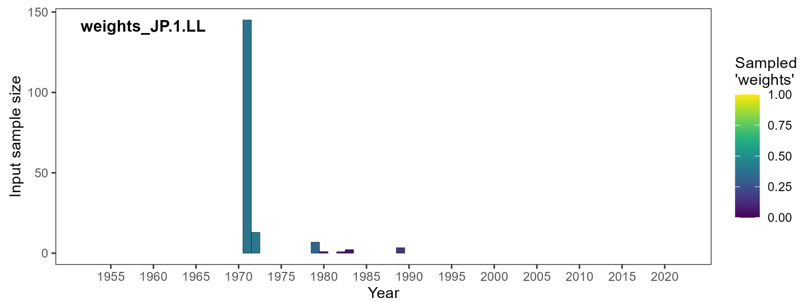


(a) Input sample sizes of weight compositions

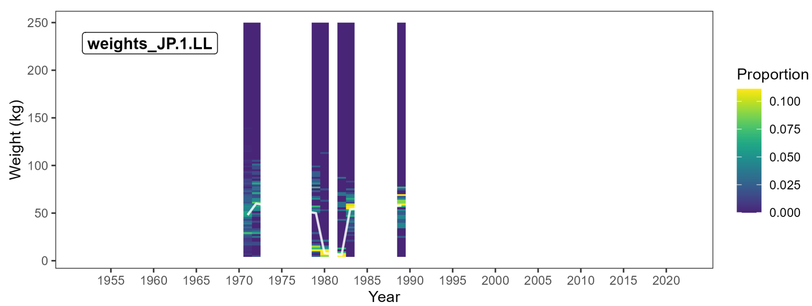


(b) Reweighted weight compositions

Figure 28: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted weight compositions with 2kg weight classes (white line provides the median weight class), for the AU extraction longline fishery in subregion 3.

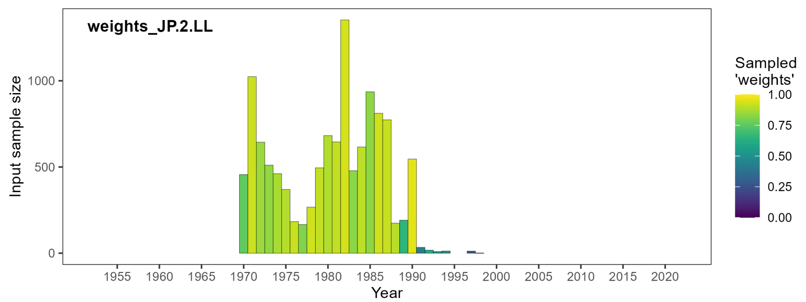


(a) Input sample sizes of weight compositions

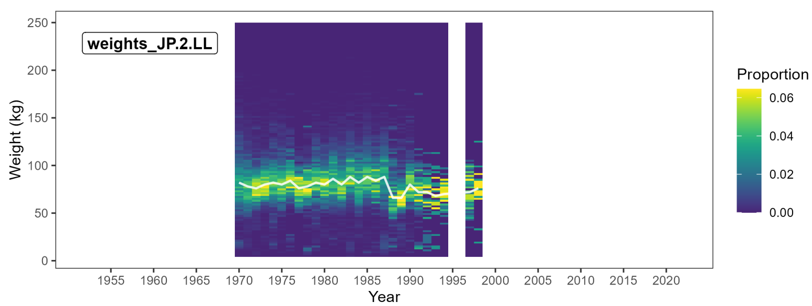


(b) Reweighted weight compositions

Figure 29: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted weight compositions with 2kg weight classes (white line provides the median weight class), for the JP extraction longline fishery in subregion 1.

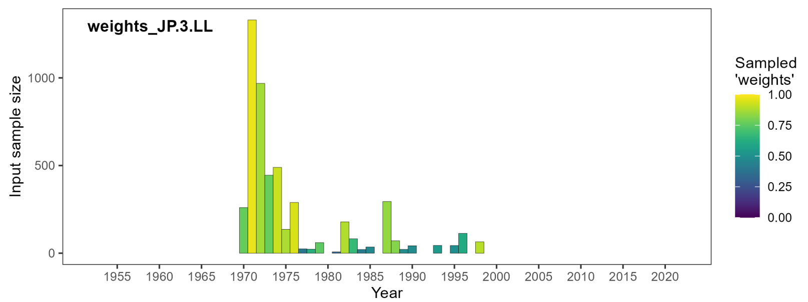


(a) Input sample sizes of weight compositions

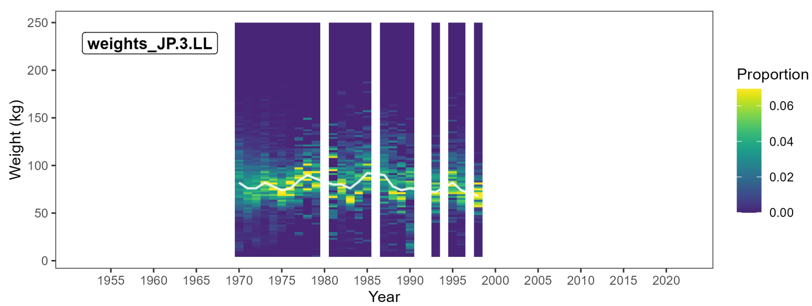


(b) Reweighted weight compositions

Figure 30: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted weight compositions with 2kg weight classes (white line provides the median weight class), for the JP extraction longline fishery in subregion 2.

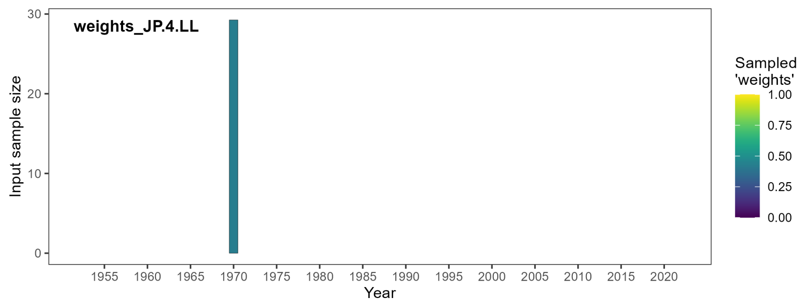


(a) Input sample sizes of weight compositions

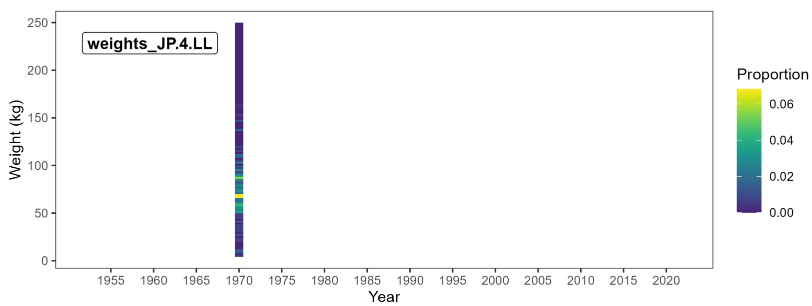


(b) Reweighted weight compositions

Figure 31: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted weight compositions with 2kg weight classes (white line provides the median weight class), for the JP extraction longline fishery in subregion 3.



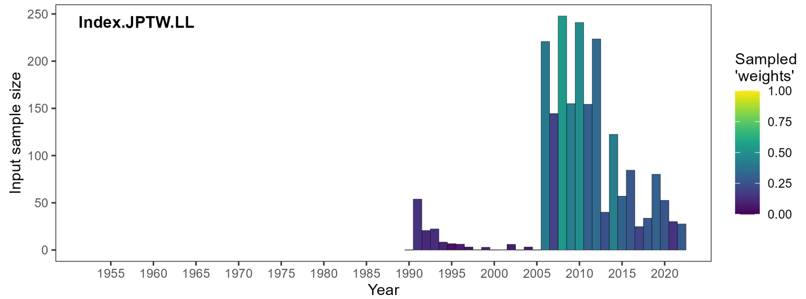
(a) Input sample sizes of weight compositions



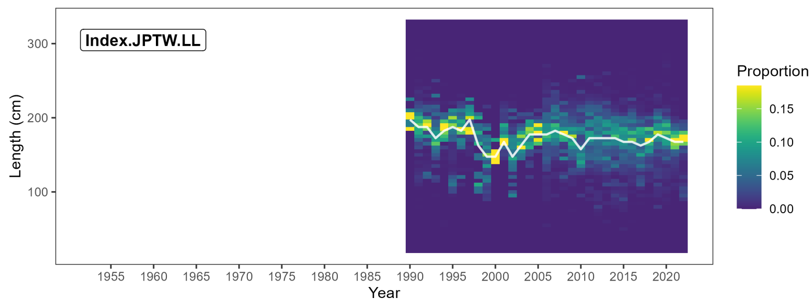
(b) Reweighted weight compositions

Figure 32: a) Input sample sizes (with bar colours providing the proportion of catch from sampled strata), and b) reweighted weight compositions with 2kg weight classes (white line provides the median weight class), for the JP extraction longline fishery in subregion 4.

8.2 Index fisheries - length compositions



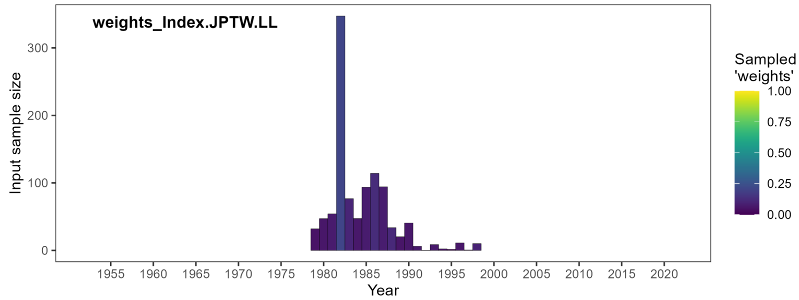
(a) Input sample sizes of length compositions



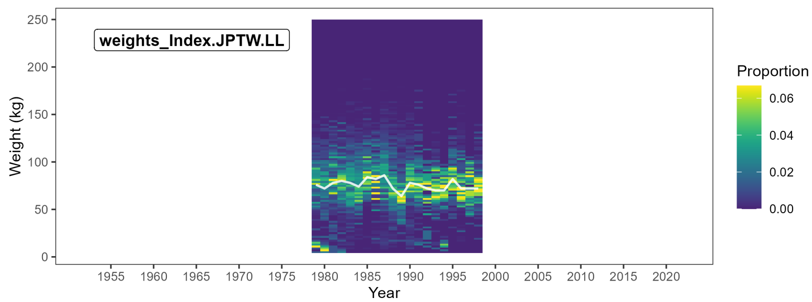
(b) Reweighted length compositions

Figure 33: a) Input sample sizes (with bar colours providing the proportion of relative abundance in sampled strata), and b) reweighted length compositions with 5cm length classes (white line provides the median length class), for the JPTW index longline fishery in the WCPO.

8.3 Index fisheries - weight compositions



(a) Input sample sizes of weight compositions



(b) Reweighted weight compositions

Figure 34: a) Input sample sizes (with bar colours providing the proportion of relative abundance in sampled strata), and b) reweighted weight compositions with 2kg weight classes (white line provides the median weight class), for the JPTW index longline fishery in the WCPO.

9 Appendix

9.1 Appendix 1: Catch and length frequency data summaries by fishery

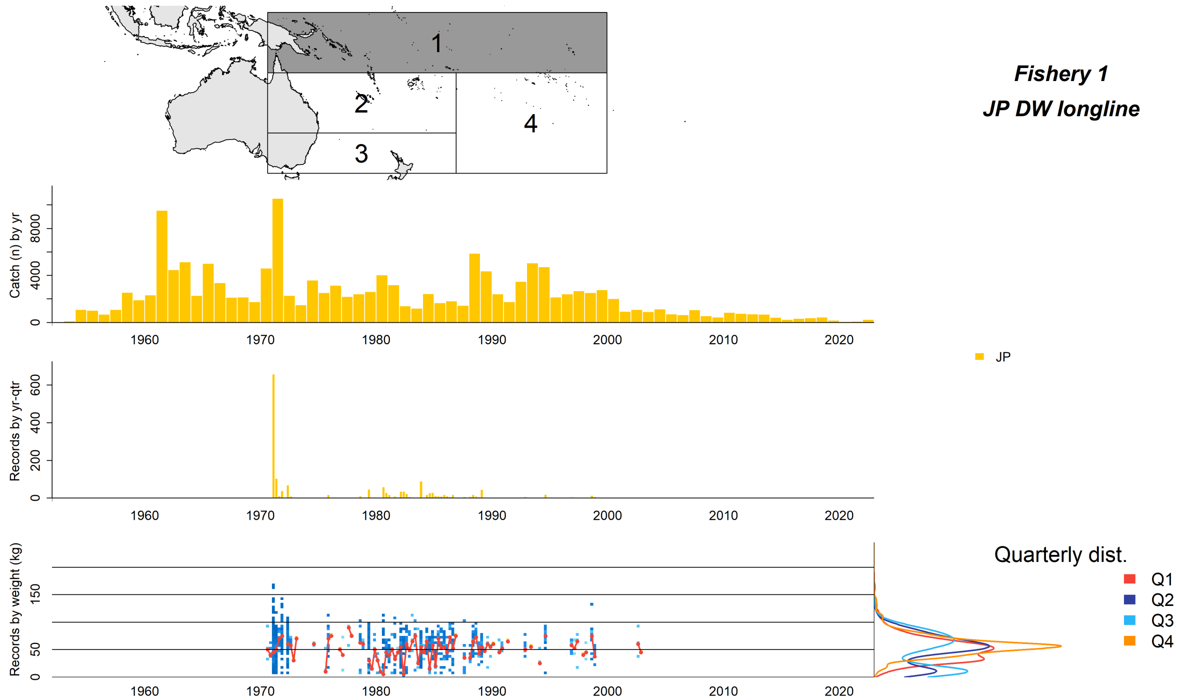


Figure 35: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

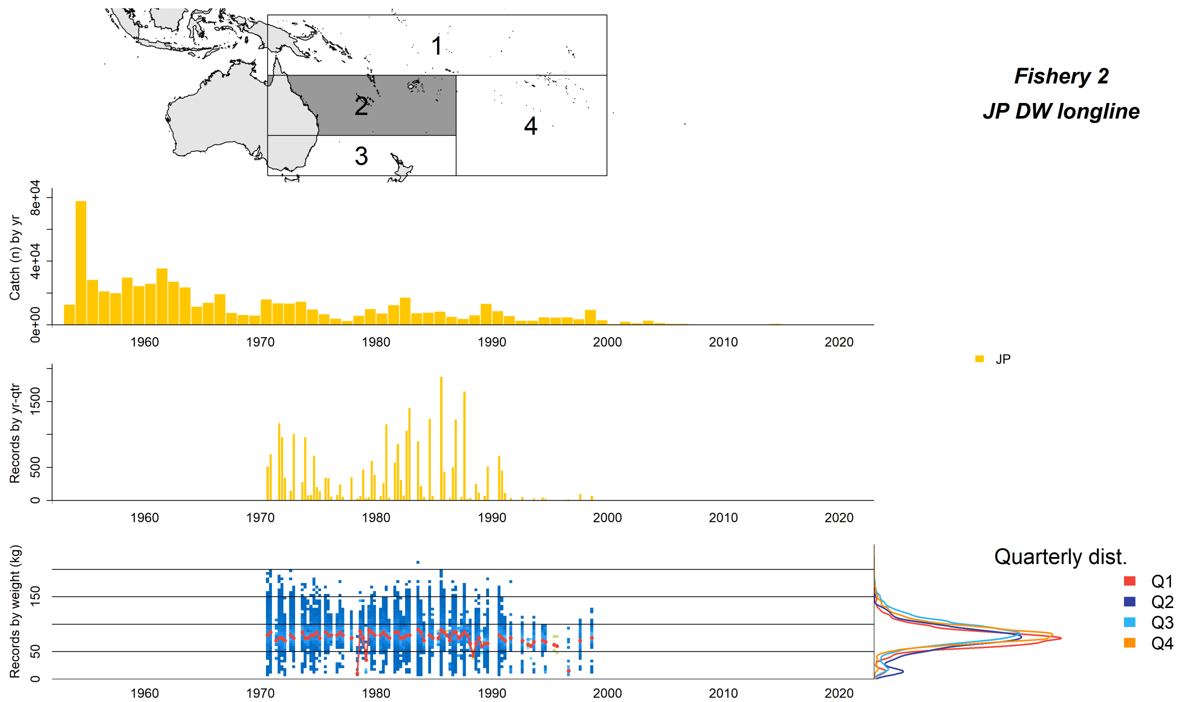


Figure 36: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

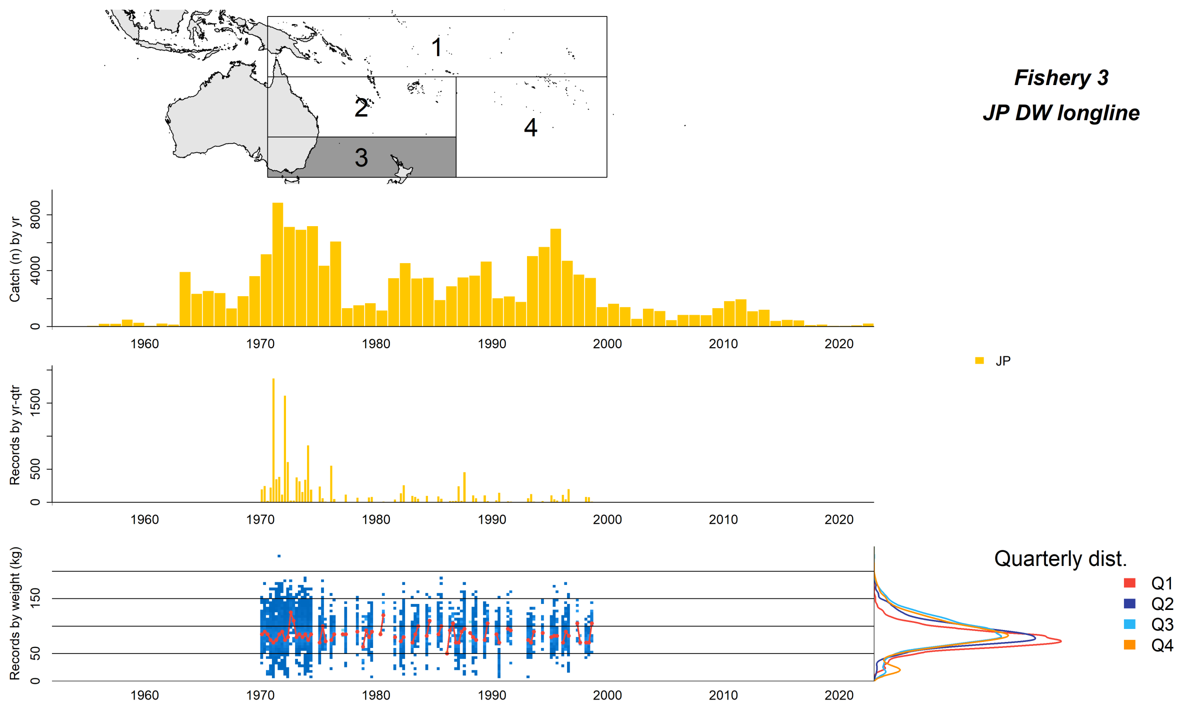


Figure 37: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

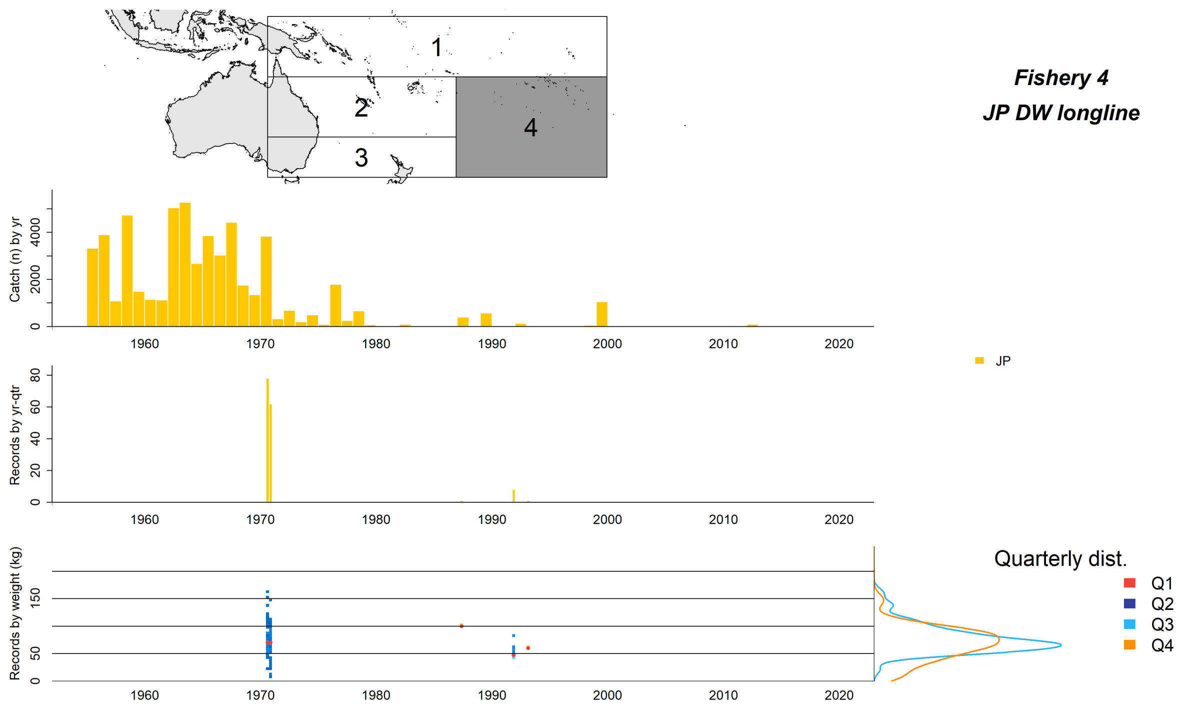


Figure 38: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

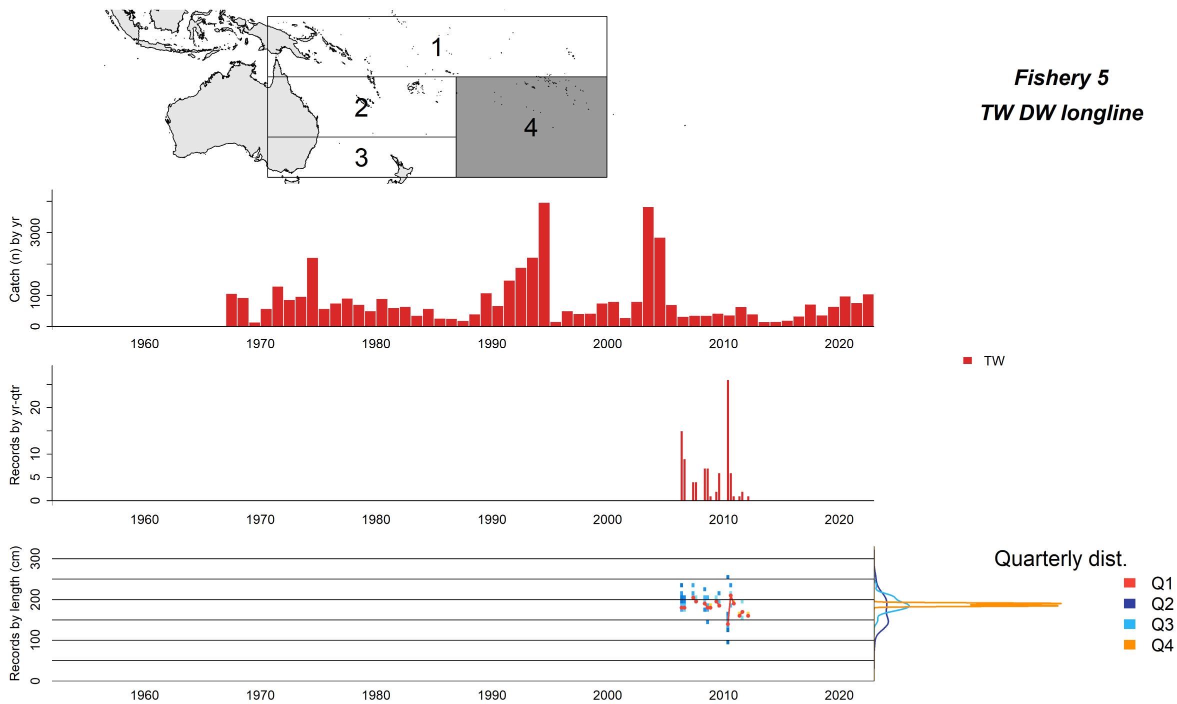


Figure 39: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by eye-fork length (cm) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

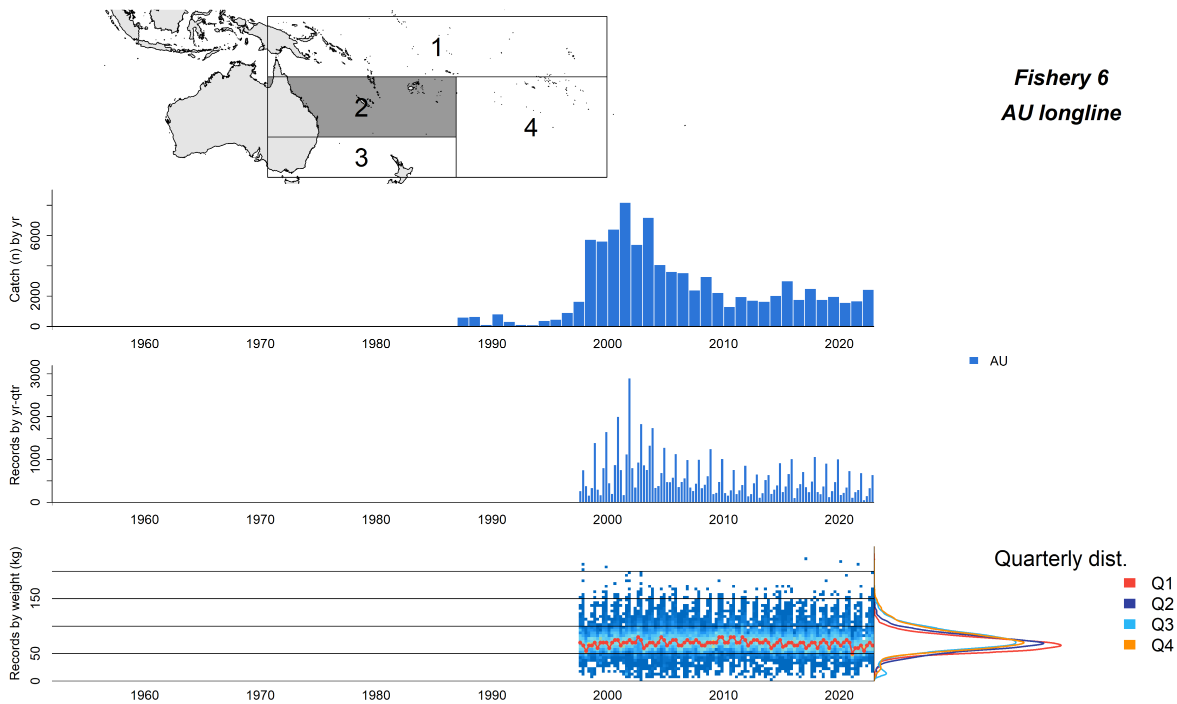


Figure 40: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

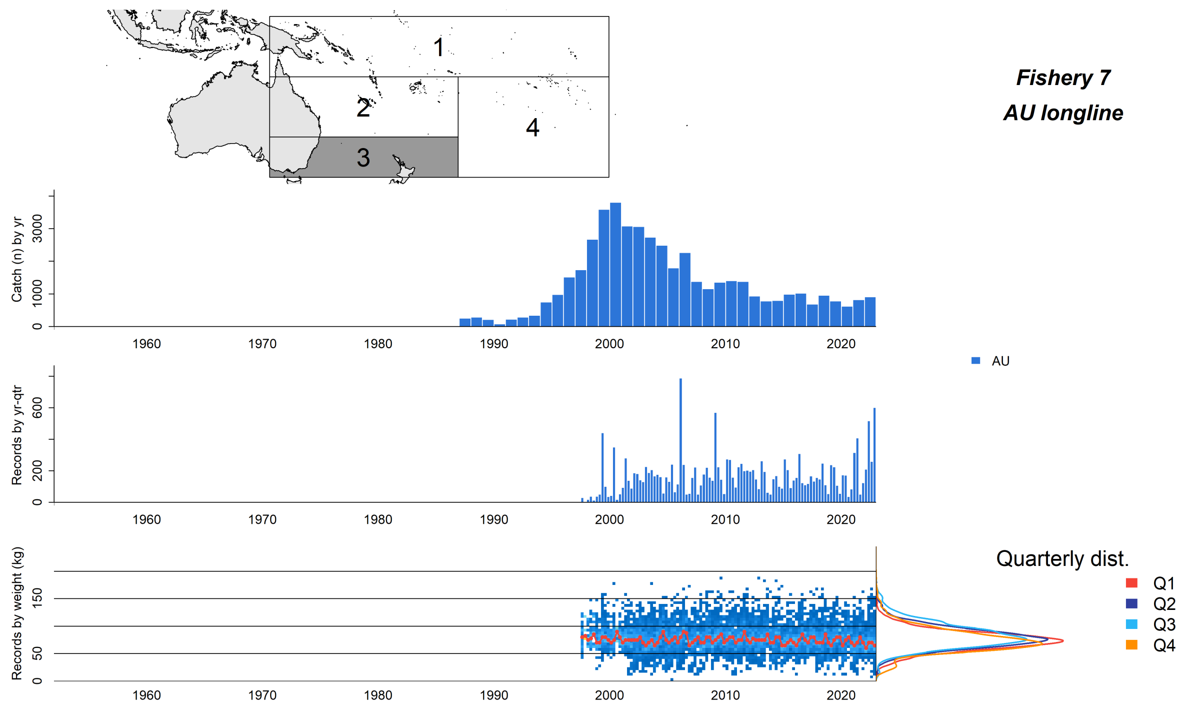


Figure 41: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

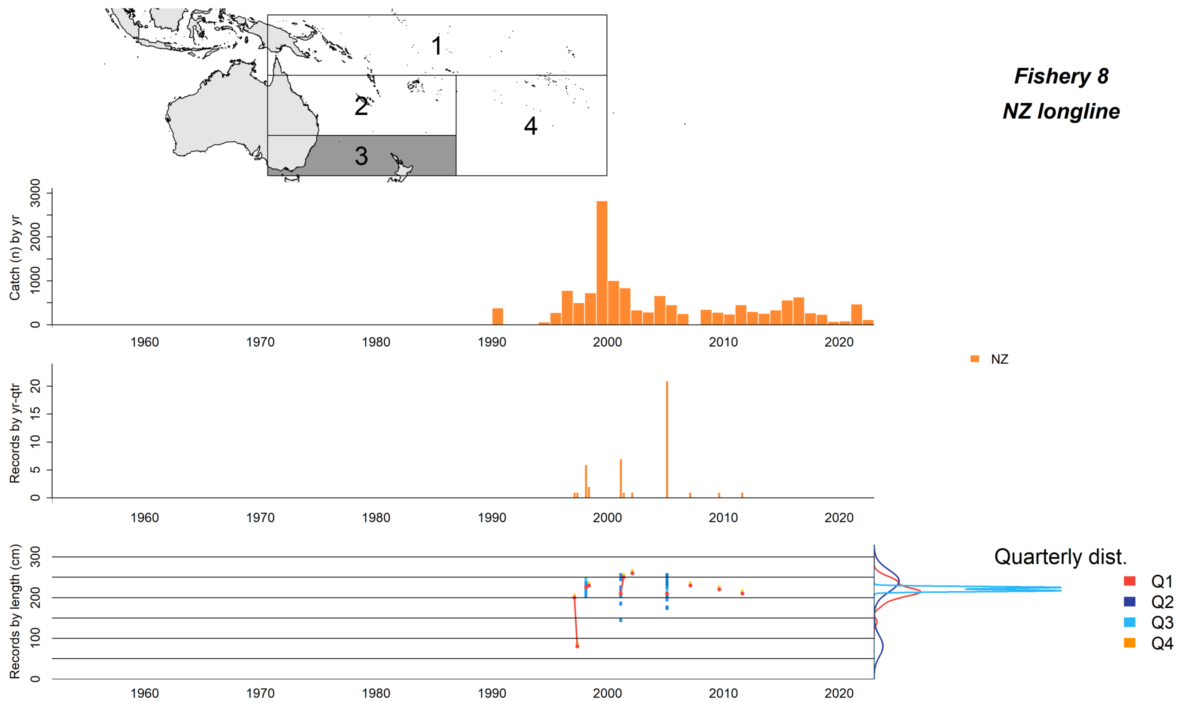


Figure 42: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

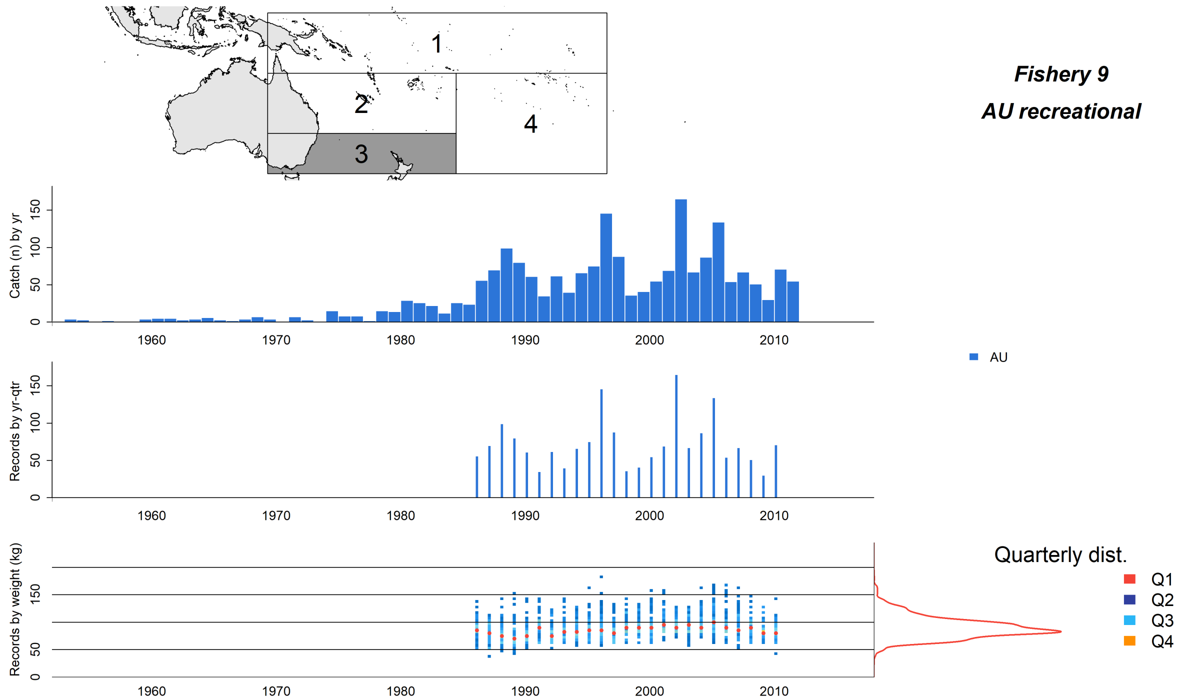


Figure 43: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this is the cumulative size composition distributions by quarter. Note that in the model the recreational fisheries are assumed to occur only in the first quarter of each year.

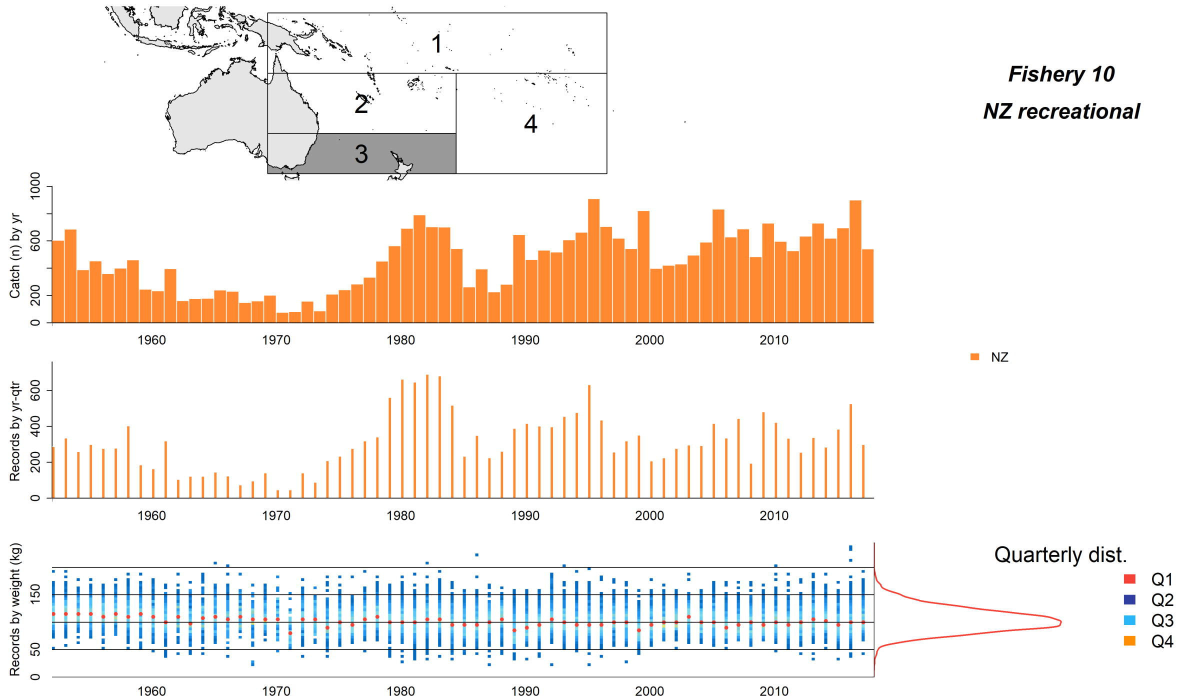


Figure 44: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this is the cumulative size composition distributions by quarter. Note that in the model the recreational fisheries are assumed to occur only in the first quarter of each year.

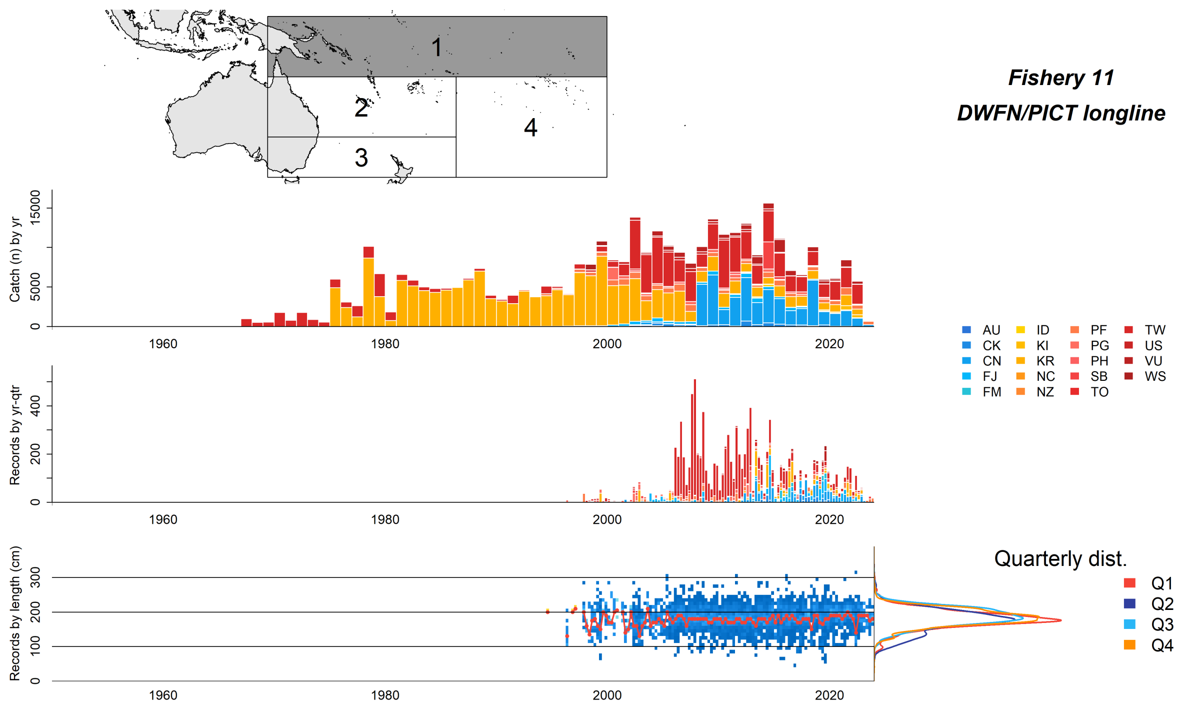


Figure 45: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

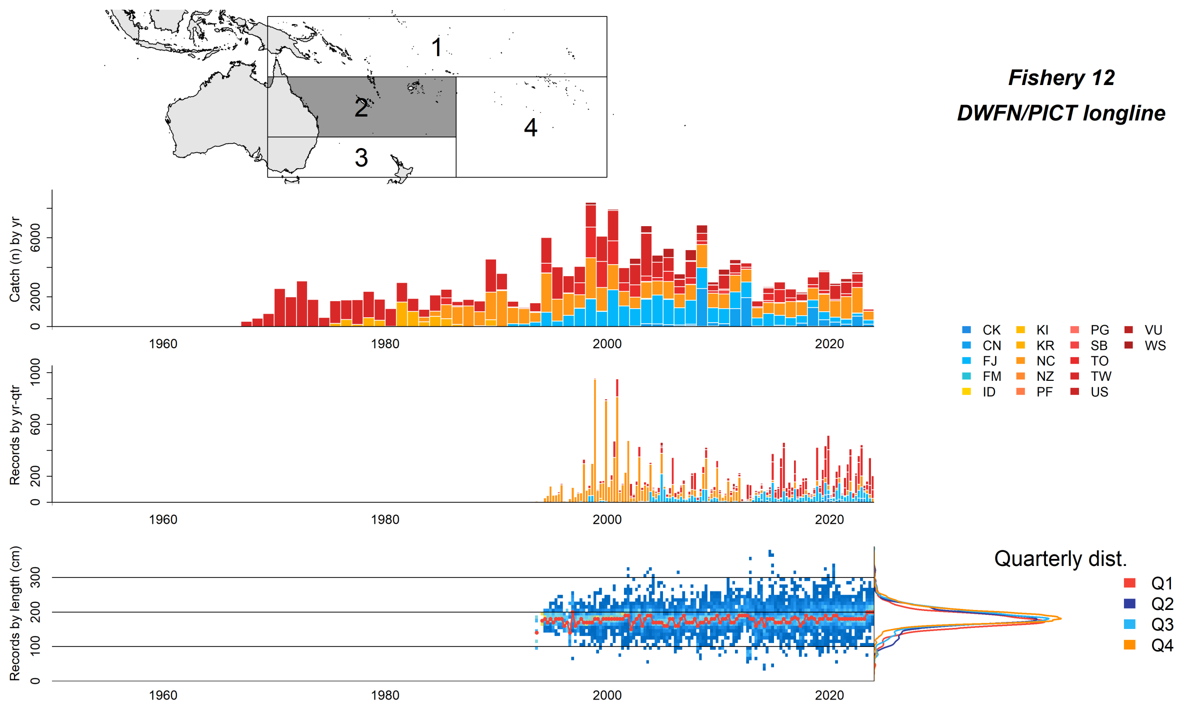


Figure 46: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

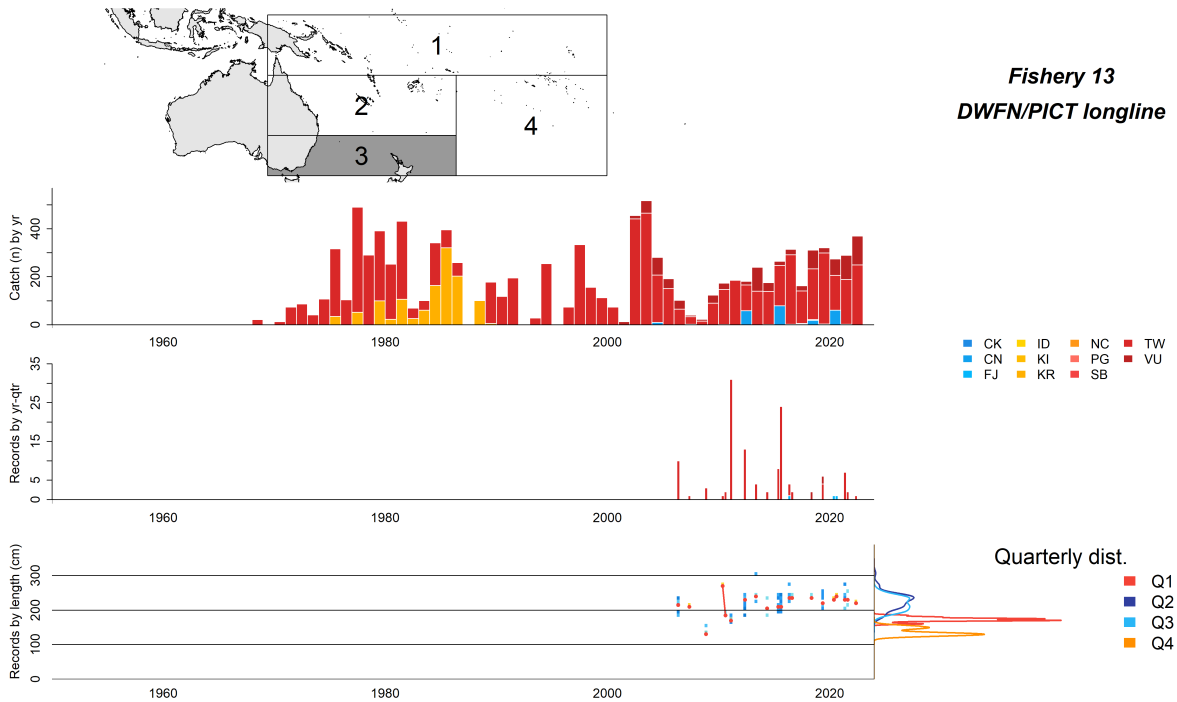


Figure 47: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.

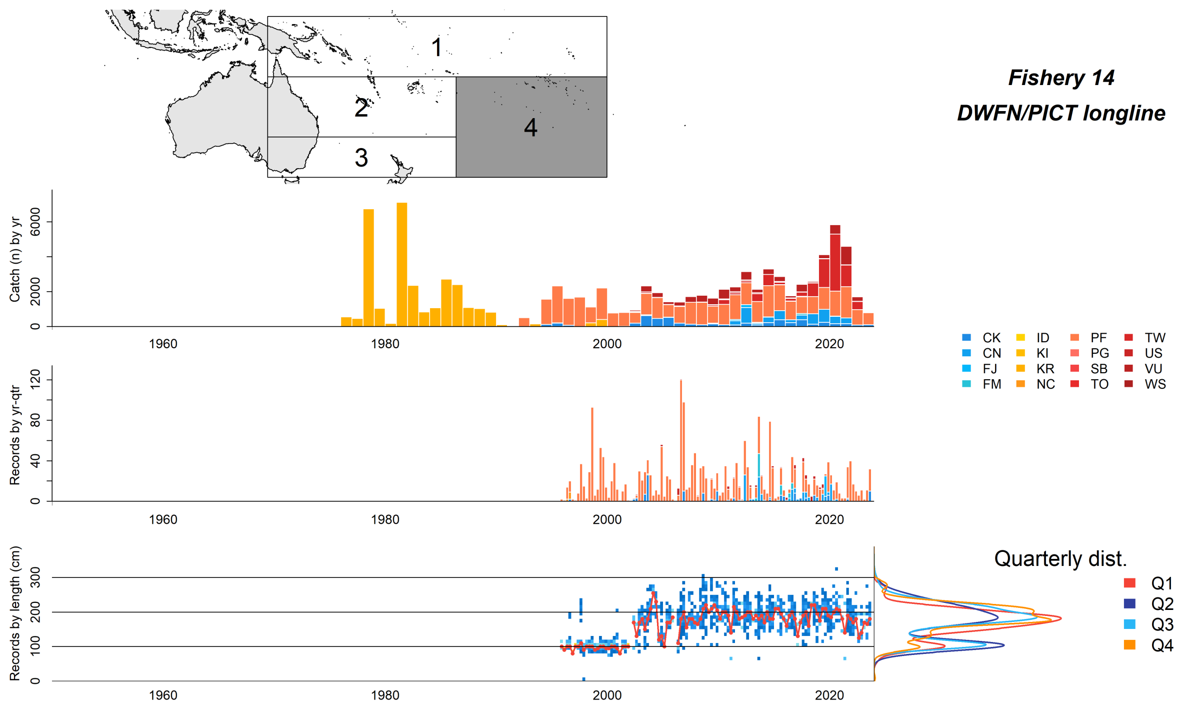


Figure 48: Summary plot showing the characteristics of the fisheries defined for the 2024 striped marlin stock assessment. The top panel indicates the sub-region the fishery was defined in. The middle two panels indicate the annual catch by country and the quarterly size composition records by country for the fishery (middle-top and middle-bottom, respectively). The lower panel shows the size composition data for the fishery by whole weight (kg) bin at a quarterly time scale with the median in each time period shown in red. To the right of this are the cumulative size composition distributions by quarter.