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Background analyses and data inputs for the 2021 South Pacific albacore tuna stock assessment

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Contents

Executive Summary **3**

1 Background information **4**

2 Regional structure **4**
- 2.1 Modifications to model regions 6
  - 2.1.1 Fishery stratification within model regions 7
- 2.2 Fishery definitions 8

3 Index fishery approach **9**

4 Standardization of catch and effort data **10**
- 4.1 Data preparation and summary 10
  - 4.1.1 Gear characteristics 13
  - 4.1.2 Species targeting 16
- 4.2 Modeling approach 17
- 4.3 Relative abundance indices 18
- 4.4 Spatial and spatiotemporal variability 21
- 4.5 Future considerations 22

5 Reweighting of size composition data **23**
- 5.1 Methods 23
- 5.2 Results 26

6 Regional weights **34**

7 Tagging data inputs **35**

8 Maturity-at-length **36**

9 Acknowledgments **36**

10 References **38**

Appendix **42**

A Catch and length frequency trends by fishery **42**

B Split CPUE time series comparison **67**

C PIT residuals **67**

D Supplemental figures from the CPUE standardization analyses **69**

E Model spatial and fishery structure background **71**

Executive Summary

This information paper provides details on the key supporting analyses and data sets used to inform the 2021 assessment model for the South Pacific albacore stock. These include:

- Changes to the spatial domain of the assessment. This year we have assessed the albacore stock across the entire south Pacific, whereas in 2018, the assessment was for the western and central Pacific Ocean (WCPO) only.
- Changes to the regional structures for the assessment. The new model structure has 4 regions, 3 in the WCPO and one in the eastern Pacific Ocean (EPO).
- Changes to the regional structure has consequences for the fishery definitions. We maintain similar definitions as for the 2018 assessment, but with modifications based on the spatial structure. Specifically, there were 21 extraction fishery and 4 index fisheries. The extraction fisheries are broken down by gear (i.e. longline, troll, driftnet), fleet (i.e. DWFN, PICT, and AU/NZ), region, and fleet area. The index fisheries are the longline fisheries from the 4 model regions.
- Fishery-specific summaries for the catch, effort, and length frequency data that were used in the assessment, and approaches used to process the length frequency data and construct the tagging input files, are all described.
- Standardization procedure of the CPUE time series to provide relative indices of abundance for the index fisheries and regional weights, are described. A spatiotemporal modeling approach was used, with vessel flag and targeting cluster - derived from a combination of species composition and hooks between floats (HBF) - were used as catchability covariates. For the EPO, only vessels flagged to Japan were retained in the catch and effort data, as it was the only fleet with reliable length frequency data.
- The reweighting of the size-composition data for extraction and index fisheries is described.
- Lastly, the approach to develop the maturity-at-length function for input into MULTIFAN-CL remains unchanged from the previous assessment, but is described for posterity.

1 Background information

Assessments of pelagic fish stocks in the western and central Pacific Ocean (WCPO) undertaken by the Pacific Community (SPC) typically require extensive background analyses, for example, investigating certain aspects of the biological or fisheries systems, or investigation of the best methods for including the input data in the stock assessment. Often, these analyses will be the result of methodological advances, the provision of new data sources, or simply the continual progression of research to improve the incorporation of information into the assessments. If these analyses are significant then they cannot be presented within the stock assessment report itself and must become stand-alone or grouped together in one or more ancillary papers.

Another source of important background information which is essential for interpreting a stock assessment is an outline of the fisheries definitions and their data summaries, particularly if there have been changes to the definitions subsequent to the previous stock assessment. These changes might be the consequence of weaknesses observed in the last assessment or subsequent analyses of fisheries data. For example, differences in size frequency data among different flagged vessels might suggest splitting the data into separate fisheries to allow flag-specific selectivity. The second common cause of modified fisheries definitions is changing boundaries of stock assessment regions.

For the last assessment, the South Pacific albacore stock was assessed in the WCPO only (Tremblay-Boyer et al., 2018a), with no formal assessment in the eastern Pacific Ocean (EPO). However, albacore tuna are perceived as one discrete stock throughout the south Pacific Ocean, and for that reason, it was proposed to conduct a south Pacific-wide assessment for 2021. As a result, the spatial domain of the assessment region has been expanded to include the entire south Pacific, and within the spatial domain the regional structures for both the index fisheries and the fishery definitions have been adjusted based on biological realism, management jurisdictions, and also recommendations from the Pre-Assessment Workshop (PAW) in March of 2021. The result is significant changes to the fisheries definitions used in the assessment.

This paper is intended to be read in conjunction with the main South Pacific albacore stock assessment report (Castillo-Jordán et al., 2021). Firstly, it outlines the changes made to the regional structures of the assessment and the consequences for fisheries definitions. It provides fisheries-specific summaries for the catch, effort and length frequency data that are utilised in the assessment. It also presents other analyses of input data in more detail than can be addressed in Castillo-Jordán et al. (2021), particularly the standardization of the CPUE indices and their associated regional weights, processing of the length frequency data, and construction of the input tagging files.

2 Regional structure

As directed under the WCPFC stock assessment schedule, the 2021 South Pacific albacore assessment spanned the entire south Pacific encompassing the southern hemisphere area of the WCPO and the EPO regions under the management jurisdictions of the WCPFC and the IATTC, respectively. The previous assessment in 2018 (Tremblay-Boyer et al., 2018a) considered the WCPFC convention area (including the overlap region) only (Figure 1). There is no previous standalone assessment of albacore in the southern EPO region; however, the 2012 South Pacific albacore assessment conducted by SPC, did include the EPO (Hoyle et al., 2012). The key structural change to the 2021 model was therefore the development of a south Pacific-wide assessment. This necessitated changes to the spatial structure as well as the fishery definitions for both the extraction and index fisheries.

To develop the current spatial structure and fishery definitions for this assessment we considered a range of information:

- the previous assessment structure (Tremblay-Boyer et al., 2018a);
- available tagging data;
- other information related to movement and population structures (i.e., models presented in review papers (Nikolic et al., 2017), expert opinions, modelling of spatial dynamics (SEAPODYM; Senina et al., 2020));
- length composition data;
- fishery coverage by fleets/gears; and
- management jurisdictional boundaries.

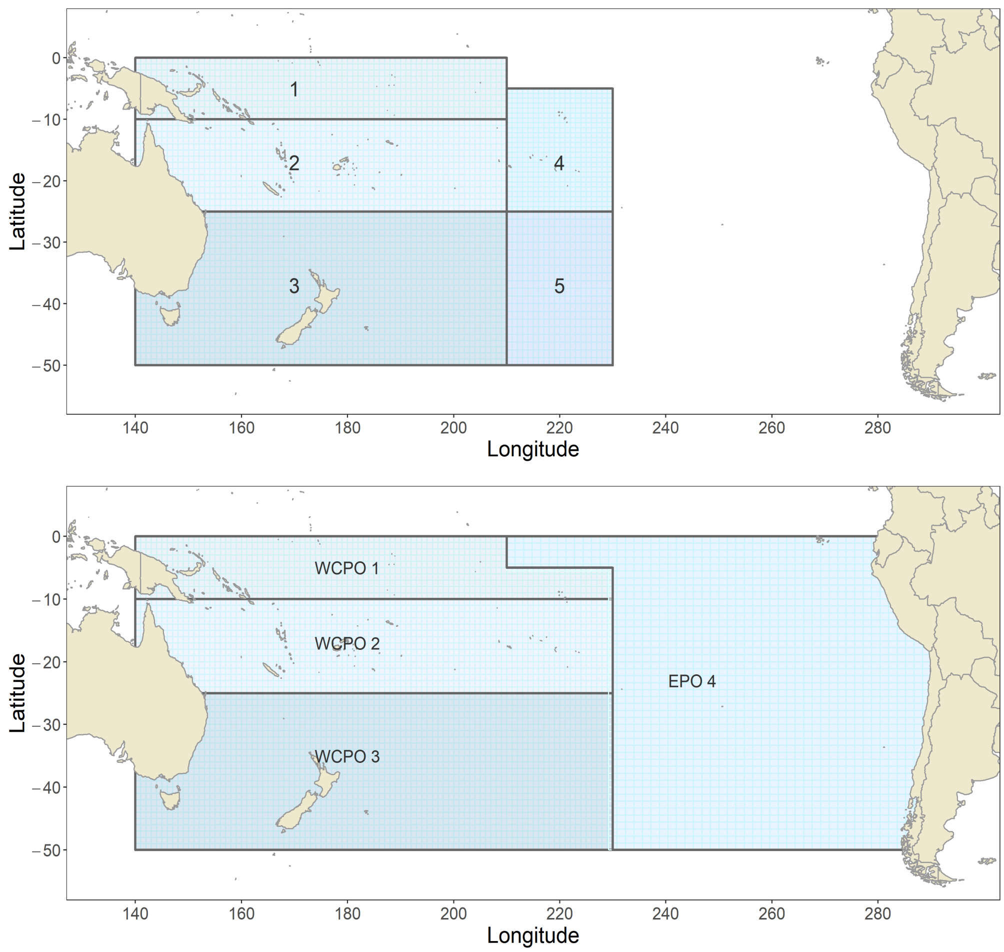

Figure 1: Albacore index fishery regional structure from the 2018 assessment model (top) and the new regional structure used in the 2021 assessment (bottom).

2.1 Modifications to model regions

The spatial boundaries for the current assessment model span from 0° to 50°S and from 140°E to the western coast of South America (approximately 90°W). The regional structure for the WCPO includes 3 regions, all spanning into the overlap region between the WCPO and the EPO (previously Regions 4 and 5 of the 2018 assessment; Figure 1). The latitudinal boundaries in the WCPO were maintained on the basis of biological hypotheses of seasonal movement, spatial structuring of the population by age, and patterns of fishing activity. Region 1 spans from 0° to 10°S and from 140°E to 130°W, excepting the region from 0° to 5°S and 150°E to 130°E, which is part of the EPO. Region 2 extends from 10°S to 25°S and 140°E to 130°W, with Region 3 encompassing the remainder of the WCPO, 25°S to 50°S, 140°E to 130°W. The EPO is considered as a single region, 130°E to 90°E, including the small section east of Region 1 (described above), due to limited knowledge about movement patterns (and a lack of tagging data to inform it).

2.1.1 Fishery stratification within model regions

Within the four model regions, sub-areas were defined to address several characteristics of the South Pacific fisheries. Specifically, an areas-as-fleets approach was used to further stratify the fisheries within each of the main assessment regions (Figure 2). The sub-areas in the overlap area were established to facilitate the exploration of management options concerning the overlap region (i.e., stock projections that apply different fishery management options to the overlap region) and also to ensure compatibility with future mixed fishery strategies in MSE modelling (e.g. Scott et al., 2021). In the overlap region, sub-areas were structured simply by allocating fleet areas to the parts of the three WCPO model regions that incorporated the overlap region. For EPO (region 4) the sub-areas were established to stratify fisheries based on spatial patterns in the size composition of the catches (Figure 3). These patterns are discussed in Appendix E and are driven by a combination of selectivity and availability differences across the model region, specifically the pattern of smaller fish being predominant in catches from cooler waters to the south east of the EPO (see Figure 3)

The approach to create the three fleet areas in the EPO followed the methods described in Lennert-Cody et al. (2010, 2020). Briefly, a regression tree-type approach was used to explore spatial and seasonal structure in length-frequency distributions. Predictors were quarter; cyclic quarter; 5° latitude; 10° longitude but year was not used as a predictor. The analysis resulted in a three area fleet structure to define the EPO fisheries (Figure 3). This structure explained 22.3% of the variability in the length composition and was better suited to the spatial catch and data distribution than more complex structures that only explained a minor amount of additional variation (i.e., 5 area options explained 25% of the variation), but suffered from low numbers of observations and low catch in some areas to inform the model.

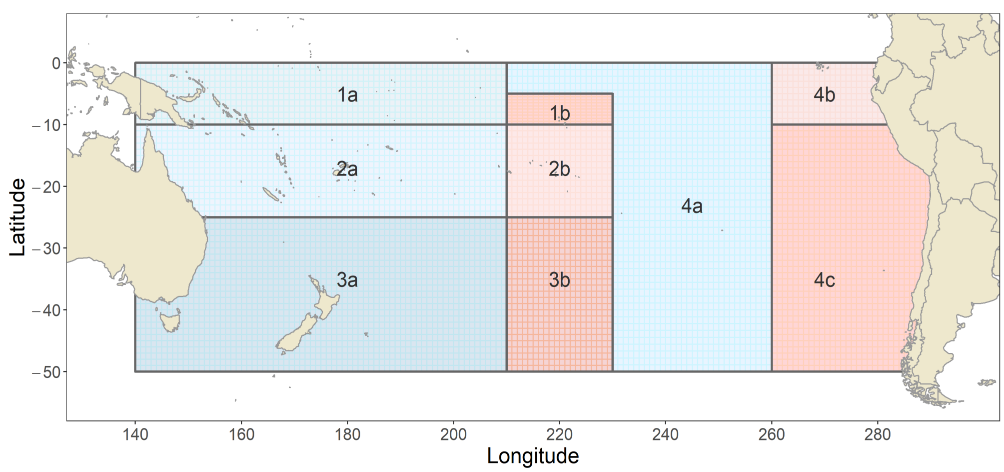

Figure 2: Map illustrating the fleet subarea delineation (red areas) within the main assessment regions.

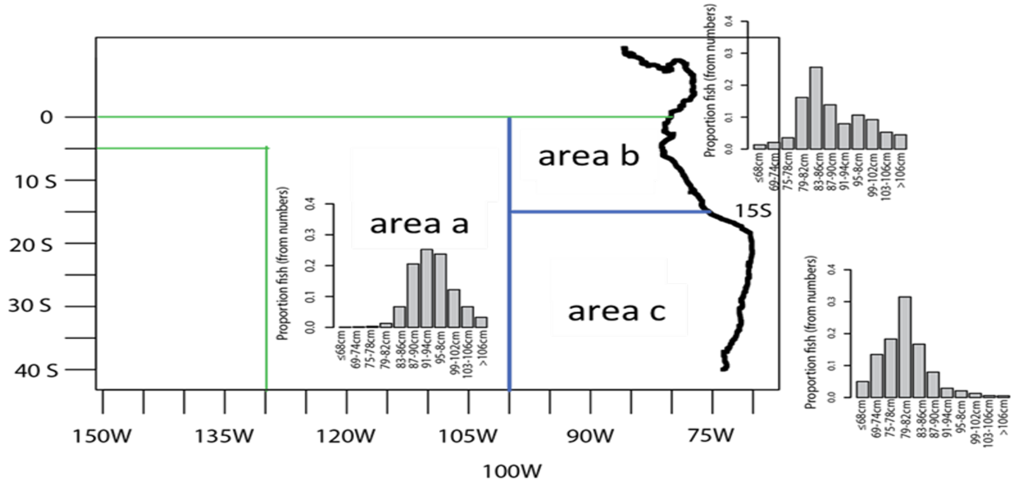

Figure 3: Illustration of subarea partition for the EPO using a regression-tree approach modified from Lennert-Cody et al. (2010), based on distribution of the length-frequency data.

2.2 Fishery definitions

Given the modifications of the spatial extent of the assessment region as well as the regional boundaries, the fishery definitions have been altered from the previous assessment. The number of fisheries has increased from 21 in 2018 to 25 for this year, with 21 extraction fisheries and one index fishery for each of the four index regions (Table 1). The index fisheries are the longline fisheries in four respective regions. The extraction fisheries are dominated by the longline sector (17 out of 21), as it is the dominant gear sector for South Pacific albacore; however, there are also two driftnet fisheries that operated in Region 3 and one troll fishery operating in Regions 3a and 4 (Fisheries 15 and 21). The catch and length frequency trends for each of the fisheries are detailed in Figures A.1–A.21 for the extraction fisheries and Figures A.22–A.25 for the index fisheries.

Fishery Number	Gear	Model Code-Fleets	Flags	Model region	Fleet area
1	LL	1-LL-DWFN	ALL	1	a
2	LL	2-LL-PICT	ALL	1	a
3	LL	3-LL-DWFN	ALL	2	a
4	LL	4-LL-PICT	ALL	2	a
5	LL	5-LL-AZ	AU/NZ	2	a
6	LL	6-LL-DWFN	ALL	3	a
7	LL	7-LL-PICT	ALL	3	a
8	LL	8-LL-AZ	AU/NZ	3	a
9	LL	9-LL-DWFN	All	1	b
10	LL	10-LL-PICT	All	1	b
11	LL	11-LL-DWFN	ALL	2	b
12	LL	12-LL-PICT	ALL	2	b
13	LL	13-LL-DWFN	ALL	3	b
14	LL	14-LL-PICT	ALL	3	b
15	TR	15-3a-All-TR	ALL	3	a
16	DN	16-3a-All-DN	ALL	3	a
17	DN	17-3b-All-DN	ALL	3	b
18	LL	18-LL-EPO1	ALL	4	a
19	LL	19-LL-EPO2	ALL	4	b
20	LL	20-LL-EPO3	ALL	4	c
21	TR	21-TR-EPO	ALL	4	a, b, c
22	LL	1-L-INDEX	INDEX	1	-
23	LL	2-L-INDEX	INDEX	2	-
24	LL	3-L-INDEX	INDEX	3	-
25	LL	4-L-INDEX	INDEX	4a	a*

Table 1: Definitions of the 25 fisheries used for the assessment modeling, based on gear, fleet, flag, model region, and fleet subarea. The index fisheries are highlighted in gray, while the remained pertain to the extraction fisheries.

Similar to the approach taken in 2018, the fleets associated with each gear sector and each region were further disaggregated based on vessel flag to improve the model fit to catch and size composition data due to differing selectivities. Flags were grouped into three main groups: distant water fishing nations (DWFNs), Pacific island countries and territories (PICTs) and Australia and New Zealand (AU/NZ).

3 Index fishery approach

The 'index fishery' approach is becoming common practice for many of the tuna stocks in the region (Tremblay-Boyer et al., 2018a; Ducharme-Barth et al., 2020; Vincent et al., 2020). This approach makes a distinction between index fisheries and extraction fisheries, where the index fisheries are used to inform the model on population trends via standardized CPUE time series, whereas the extraction fisheries are only associated with catch and no effort, and are used to scale the estimated abundance (Methot and Wetzel, 2013). In addition, this approach allows the size data to be used to remove fish at the proper sizes, but also to inform the model on fluctuations in abundance and size composition.

4 Standardization of catch and effort data

A spatiotemporal modeling approach was used to produce relative abundance indices for the four index fisheries (Figure 1), using the Pacific-wide operational longline data set. This data set extends back to 1952 and encompasses historical fishing information for distant-water fishing nations (DWFNs), Pacific island countries and territories (PICTs), as well as 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, 2018b; Ducharme-Barth and Vincent, 2020). In 2018, Tremblay-Boyer et al. (2018b) used these operational longline data to standardize longline catch and effort for the South Pacific albacore assessment in the western and central Pacific Ocean (WCPO) (Tremblay-Boyer et al., 2018a). This was the first application of a spatiotemporal modeling approach for South Pacific albacore, using the *VAST* R package (Thorson et al., 2015). The current approach builds upon this previous analysis, employing similar data filtering criteria and model structure, while noting the expansion of the spatial domain for the 2021 assessment.

4.1 Data preparation and summary

The full operational longline data set consisted of approximately 11.2 million records, of which, 5.8 million are associated with fishing activity across the south Pacific Ocean. We restricted the time series to span from 1960 through 2019. Data were broadly filtered to remove improbable data values representing extreme outliers or potential reporting errors. The filtering criteria included removing sets with: associated positions over land; number of hooks fished per set below 150 and above 5000; number of hooks between floats greater than 50, and sets with no catch of the four main target species (albacore, yellowfin tuna, bigeye tuna, and swordfish). Sets by the E.U. (Spanish) fleet were also removed as the number of hooks between floats was missing for all observations, and catch was initially reported in metric tonnes as opposed to numbers, as is used in this analysis (although work to convert these catches to number of fish has been carried out). The E.U. (Spanish) fleet has primarily targeted swordfish, and had minimal catches of albacore.

In the EPO, we retained sets from the Japanese fleet only because it was the only fleet with a suitable time series of length composition data. In the EPO, the Japanese fleet has been one of the major contributors for much of the historical time series when most EPO longline effort was focused in the equatorial waters targeting bigeye tuna. More recently, the fleet structure has diversified, with vessels flagged to Vanuatu, Chinese-Taipei, and China fishing in the more southerly waters targeting albacore. The Japanese effort has waned substantially in recent years, with most of their effort remaining concentrated in the tropical waters. As a result, there was concern over potential bias associated with applying the length composition data from the Japanese fleet to catch rates from all fleets, as the other fleets are largely fishing in different areas and are likely catching smaller size classes. The result, however, was the removal of observations associated with the majority of the catch for the past decade (Figure D.1). Improving the availability and quality of length composition data from all fleets would allow for better utilization of the full data set in the future.

Lastly, we imposed a minimum data requirement by strata (time and location combination) such that time periods were removed if there were fewer than 50 sets per year-quarter, and 5°x5° spatial cells were removed is there were fewer than 20 sets made. The resulting data set included approximately 4.8 million records, with vessels flagged to 21 different nations, including DWFNs, PICTs, as well as fleets from Australia and New Zealand. Figure 4 illustrates the distribution of fishing effort (sets) through time by the different flag states.

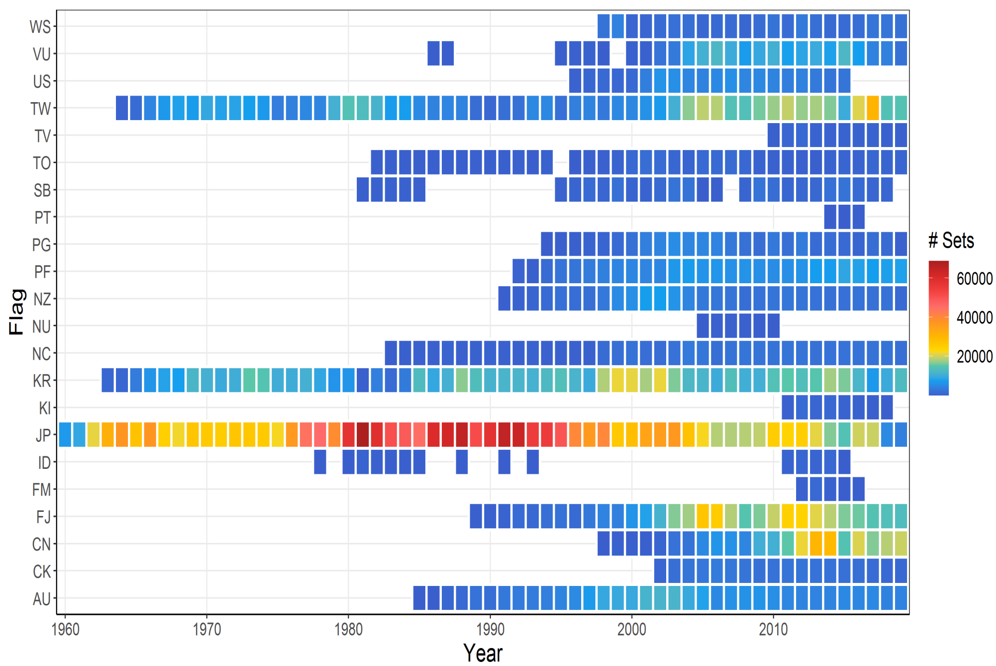

Figure 4: Distribution of fishing effort (# sets), by vessel flag state, in the filtered data sets from 1960-2019.

Observed albacore catch rates varied across space and through time (Figure 5). In the early part of the time series, relatively high catch rates were observed from about 5 to 10°S throughout much of the WCPO and into the western portion of the EPO, with the highest catch rates concentrated in the southern WCPO from 25-35°S. Through time, catch rates have generally decreased, although there appeared to be an increase in longline effort (Figure 6) and catch rates in the western-central EPO beginning around the 2000s. Longline effort has generally increased through time (Figure 6), with the highest effort, especially within the WCPO, exerted during the most recent two decades.

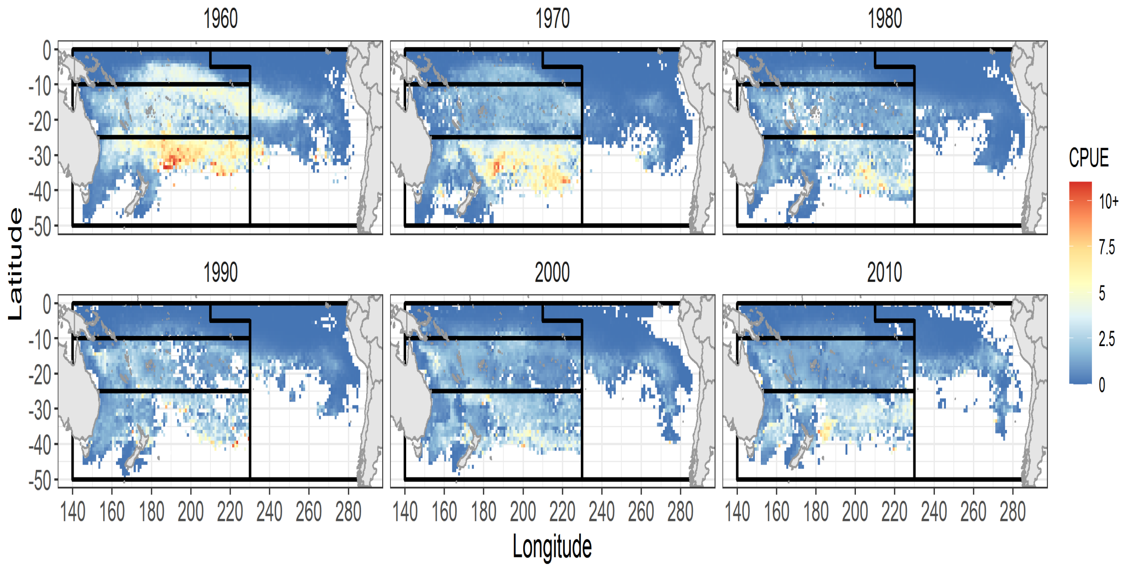

Figure 5: Observed mean albacore catch per unit effort (#/100 hooks) from 1960-2019, aggregated across fleets and plotted by decade.

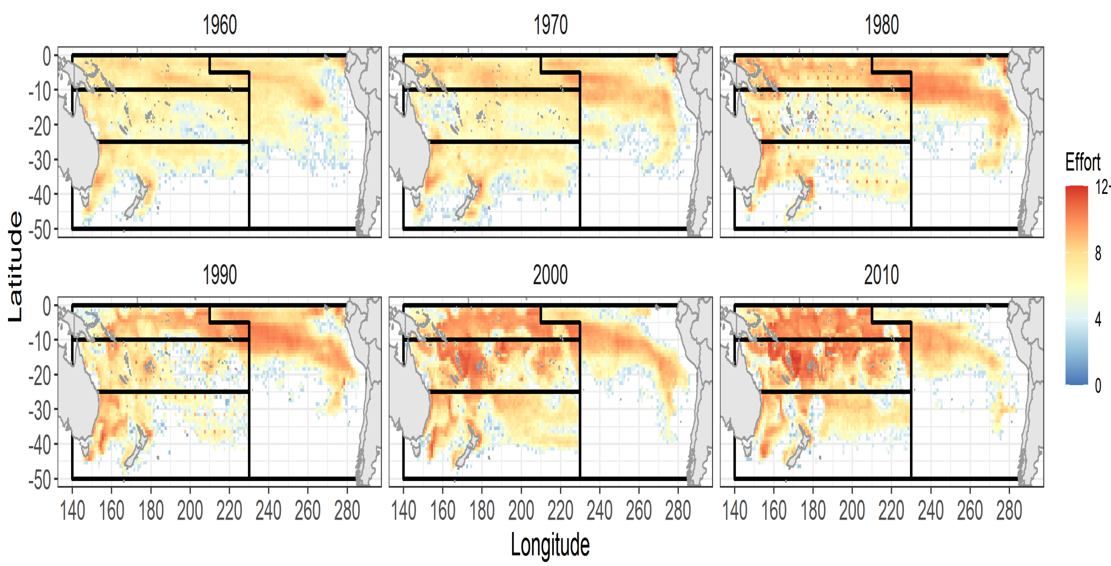

Figure 6: Observed longline fishing effort (100 hooks; log scale) from 1960-2019, aggregated across fleets and plotted by decade.

The longline fishery in the south Pacific was historically dominated by the DWFNs (i.e. Japan, Korea, Chinese-Taipei), largely fishing for bigeye and yellowfin tuna in the tropical waters and albacore in the more temperate waters to the south. Around the mid-1990s, the fleet composition began to shift towards greater participation by PICTs, at least in the WCPO. There has been an increase in albacore fishing in the EPO, likely in association with declining bigeye catches, but overall, the species composition by index region has remained fairly stable through time (Figure 7).

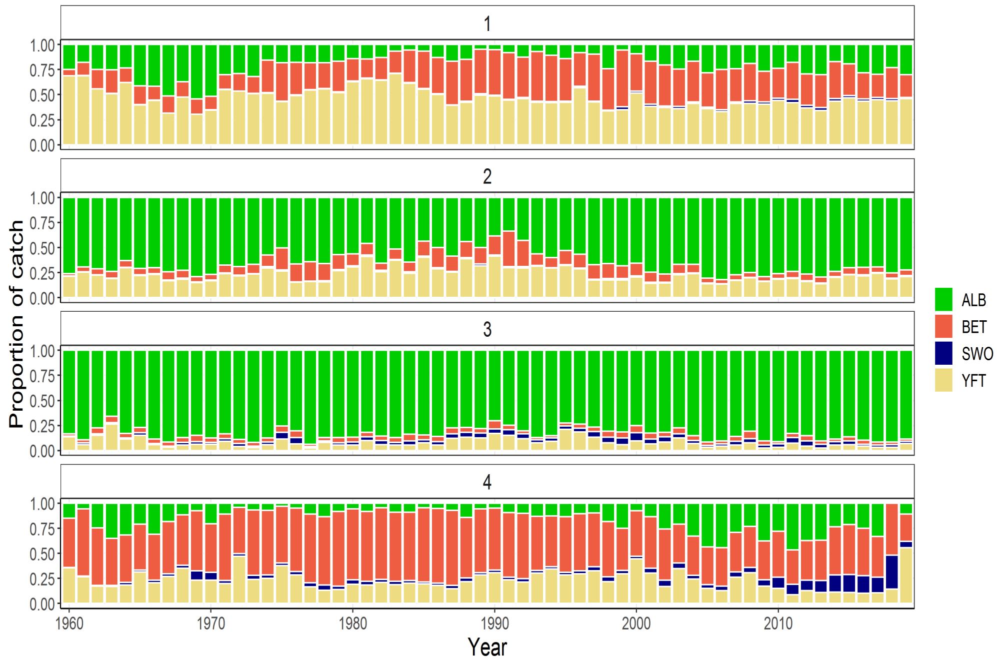

Figure 7: Proportion of the four main species harvested (ALB = albacore tuna; BET = bigeye tuna; SWO = swordfish; and YFT = yellowfin tuna) in the south Pacific longline fishery, by year and index region, from 1960-2019.

During the 2021 Pre-Assessment Workshop (PAW), there were discussions around splitting the time series into an early (1960-1995) and more recent time period (1994-2019). These decisions were motivated by the perceived importance of a purported fleet-wide adoption of monofilament mainline material; a lighter material than was used previously (e.g. natural fibers; Ward and Hindmarsh, 2007). This gear shift, combined with use of a mainline drum and line shooter technology, enabled greater flexibility and perhaps control over the gear setting and fishing depth. In addition, the operational data are more comprehensive in the contemporary time period, potentially enabling a more informed standardization model (e.g. inclusion of individual vessel effects, flag, oceanographic variables). Preliminary analyses were carried out and indices developed from the full time series were compared to the indices generated from the more complex standardization model for the recent time period only. The indices showed very similar trends, suggesting that the split had minimal effect as did the additional covariates. Therefore, we have opted to retain a single time series standardization, spanning from 1960-2019; however, we suggest that future analyses explore the possibility and implications of using split CPUE time series as model inputs.

4.1.1 Gear characteristics

The operational longline data are largely absent of detailed vessel and gear characteristics that could be valuable in a standardization model, However, hooks between floats (HBF) is one gear characteristic that is largely available for many of the fleets throughout the time series. The number of hooks between floats (HBF) on the longline mainline was once considered an important gear characteristic, as it largely determined the fishing depth of the gear. More hooks were set on the mainline to fish deeper depths, and fewer were used to fish closer to the surface. Over the time series there has been a dramatic shift in the number of HBF used by the longline fleet (Figure 8). In the 1960s most of the sets are configured with 1-5 HBF, with a subset configuring their gear with 6-10 HBF for deeper sets. By the 1990s, there were observations of vessels using up to 40 HBF while HBF of less than 5 had all but disappeared, excepting a small portion of sets largely associated with swordfish targeting. This pattern of increasing HBF continues to the most recent time period, where HBF throughout the main albacore fishing grounds ranged from about 15-40, with the lower values mostly observed in the coastal regions around Australia and New Zealand and to a lesser extent off the Peruvian coast. The shift towards greater HBF occurred around the same time as the shift towards monofilament mainline material. Although there have been dramatic temporal shifts in HBF, it remains one of the only reliable gear characteristics available to explain some of the variability in catchability associated with gear configuration. Therefore, there was interest from the PAW in including it in the standardization procedure. HBF values were grouped into 5 hook bins, ranging from 1-5 to 46-50.

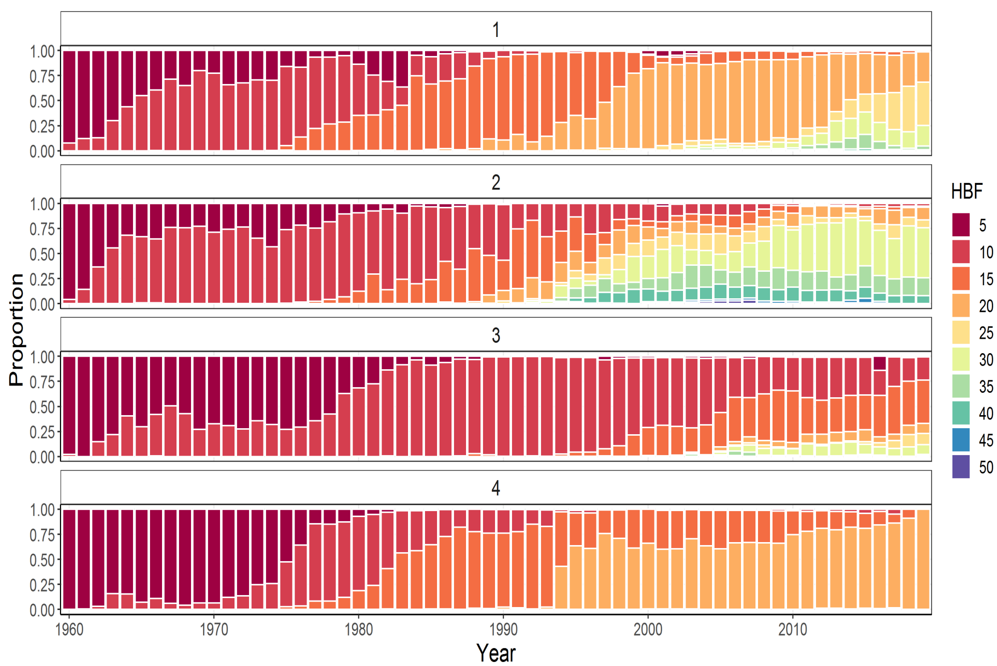

Figure 8: Time series of HBF values by index region, showing a general trend towards higher HBF values in the more recent time periods. There is a notable and rather abrupt shift in HBF around the time of the purported shift to monofilament mainline material (mid-1990s).

Although HBF has largely been reported throughout the time series, it was missing from about 23% of the set records. Therefore, data imputation was required to model the full data set. We used a random forest approach (Breiman, 2001) to predict the missing values, based on data for which HBF values were assumed to be reported accurately. Here, we used the R package *randomForest*

(Liaw and Wiener, 2002) to predict HBF based on the year, month, latitude, longitude, number of hooks fished, vessel flag, proportion of the four main harvested species (albacore, yellowfin, bigeye, and swordfish), and total catch value, using 500 trees. Due to the size of the data set and associated computational demands, we used a bootstrap approach to subsample the full data set with reported HBF (approximately 3.7 million records) at a rate of about 30%, to then predict the missing observations (approximately 1.4 million records). We repeated this procedure 10 times and selected the mode of the estimates as the predicted HBF.

The random forest approach was tested prior to imputing data values. We subsampled the data (stratified by year and 5°x 5° cell) set with reported HBF (at a rate 20%), and then split the subset into a training and testing data set (results were robust to the random subsampling and sampling rate, evaluated through a series of sensitivities). The training data set represented 80% of the subset, and was used to develop the model, and the testing data set represented 20% of the subset. The HBF values for the testing set were then predicted by the model developed with the training data set, and the results were compared to the reported HBF. Overall accuracy was 88% with a Cohen's κ statistic of 85%. The HBF bins with fewer observations (i.e. 46-50) were predicted less well, but even so, when the reported HBF was not predicted precisely, it was typically assigned to a neighboring bin (Figure 9). Given the binning of HBF into 5 hook groups, this prediction error was not viewed as a major limitation to the analysis.

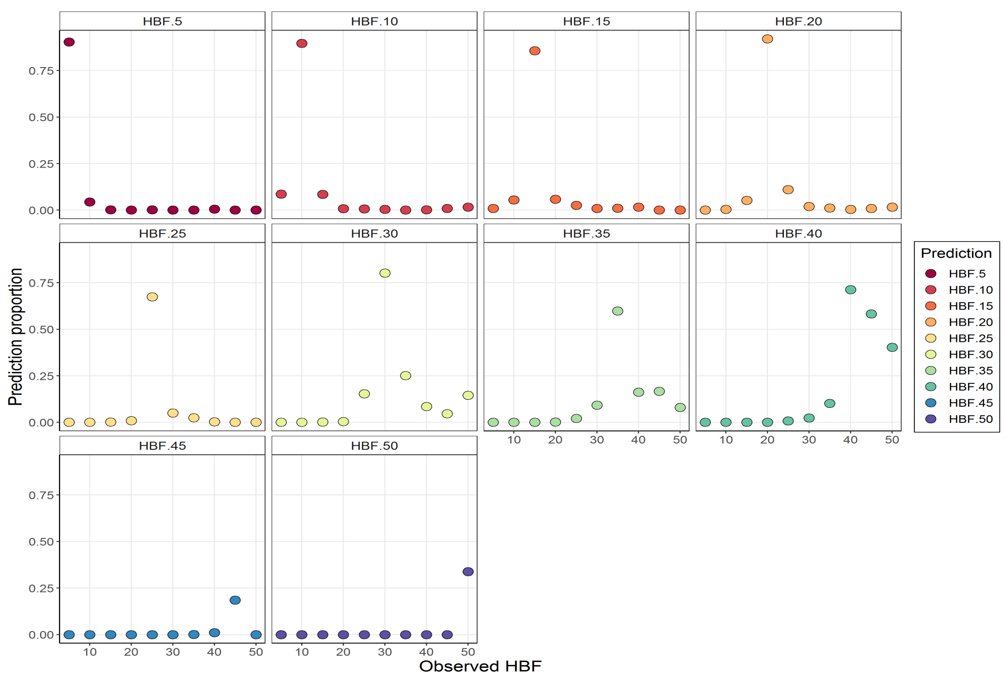

Figure 9: An illustration of the HBF predictions (different panels) relative to the observed HBF values (x-axis), for the HBF imputation evaluation. It is clear that most of the values are predicted correctly, but when the precise bin is predicted incorrectly, it it common that a neighboring bin was predicted instead.

4.1.2 Species targeting

Targeting behavior is an important consideration for CPUE standardization models, and has been the focus of much research (e.g. Hazin et al., 2007; Chang et al., 2011; Winker et al., 2013). For the south Pacific longline fishery, targeting has not only been dynamic in space, but also through time, as the abundance and demand for alternative species has waxed and waned. Inference about a target species for each set, without explicit information from skippers/fishing masters declaring their targeting intention, is often derived from the species composition of the catch (Tremblay-Boyer et al., 2018b). The problem with this approach, is that the synthetic targeting variable may confound changes in abundance, as targeting does not necessarily directly map to the resulting catch. For example, fishers may target bigeye tuna, as they generally command a higher market price, but that does not necessarily imply that bigeye will be the dominant species in the catch, even if the gear and fishing strategy is executed as intended (Chang et al., 2011). In addition, species composition can be misleading with respect to longline targeting intention due to factors such as current speed and subsequent gear shoaling (Bigelow et al., 2006). Despite these caveats and considerations, targeting can be highly influential when developing indices of abundance, and effort must be taken to account for these changes, even if the data are imperfect, as the consequence of omitting it all together may be more consequential.

Here, the targeting cluster was derived in a similar manner as in 2018 (Tremblay-Boyer et al., 2018b), except that the k-means clustering algorithm was applied to the full data set simultaneously, as opposed to the index regions separately. This minor change is expected to better capture the relative targeting practices across the entire region. We calculated the proportion of albacore, yellowfin, bigeye, and swordfish, at the 'trip' level to smooth through some of the set-level variability. The trips were then clustered based on relative proportions of the catch and HBF[4]. Preliminary analyses suggest that using three levels for the targeting covariate may be appropriate, as approximately 76% of the variation in the species composition and HBF data was explained.

It should be noted that alternative clustering approaches were evaluated, based on recommendations from the Pre-Assessment Workshop (PAW). Using the same input data, we used the *hclust* hierarchical clustering method from the R package *fastcluster* (Müllner, 2013) as well as a clustering of PCA axes (Winker et al., 2013), using the non-hierarchical *clara* clustering approach from the R *cluster* package (Maechler et al., 2019). It is difficult to objectively evaluate the different approaches, because we do not know the true targeting behavior. Therefore, we largely have the species composition with which to evaluate the performance, as we assume that the clusters would generally map to the observed species composition. With this general evaluation criterion in mind, the PCA clustering approach produced results which were hard to justify, and seemed to be disconnected from what was observed. The *hclust* procedure was performed on a subset of the data and compared with the *kmeans*. The two approaches performed similarly on subsets of the data, but the *hclust* has computational limitations, and it was not possible to apply to the full data set. Based on these comparisons and for computational efficiency, we elected to proceed with the *kmeans* clustering approach, but additional attention should be given to this important component

[4] A min-max transformation was applied to HBF prior to clustering to ensure values were comparable to the scale as the catch proportions, i.e. between 0 and 1

of the analysis.

4.2 Modeling approach

The model was fit to data from 1960-2019, and as a result, there were limited data available to inform gear or vessel-based characteristics or unique vessel identity associated with each set. Here, we explored models with combinations of targeting cluster, flag, and HBF fitted as a spline as catchability covariates. The models with HBF did not converge, and therefore were not considered.

Here, a delta-gamma spatiotemporal model was used, as opposed to a delta-lognormal, as the gamma error distribution has been shown to outperform the lognormal when the underlying error distribution is misspecified (Thorson et al., 2021). Specifically, the linear predictors for encounter probability and magnitude of positive catch rates (model component, encounter probability or positive catch rate) are modeled for knot s and time step t, with the respective link functions (i.e. logit for the encounter probability and log link for the positive catch rates).

Encounter probability:

$$y_i \sim Bernoulli(p_i)$$

$$logit(p_i) = \beta \text{YrQtr}_i + \omega_1(s_i) + \phi_1(s_i, t_i) + \gamma \text{X}_i + \epsilon_1$$

Positive catch component:

$$c_i \sim \Gamma(\sigma^{-2}, \eta_i \sigma^2)$$

$$log(\eta_i) = \beta \text{YrQtr}_i + \omega_2(s_i) + \phi_2(s_i, t_i) + \gamma \text{X}_i + \epsilon_2$$

where σ is the coefficient of variation of measurement errors for positive catch rates (Thorson and Ward, 2013; Thorson et al., 2015), β is the year-quarter effect, $\omega(s_i)$ is the spatial effect, $\phi(s_i, t)$ is the spatio-temporal effect, and γ represents the fixed catchability coefficients for catchability covariates X. The spatial variation terms $\omega(s_i)$ are assumed to come from a Gaussian random field, and treated as random effects, assuming a Matern covariance matrix to account for spatial autocorrelation.

$$\omega_m \sim \text{MVN}(0, \sigma^2_{\omega m} \mathbf{R_m})$$

Separate decorrelation rates $\mathbf{R_m}$ (related to the anisotropy) were estimated for each model component (Thorson, 2019). The spatio-temporal random effects $\epsilon(s_i, t)$ 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.

Predicted CPUE at each knot in each time period $d(s, t)$ was estimated by obtaining the product of the back-transformed linear predictors, after dropping the catchability terms. The abundance index is then calculated as the sum of the area-weighted CPUE

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

where $a(s)$ is the area associated with knot s. Regional 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 (Thorson et al., 2016).

Given the computational constraints associated with a large data set, a long time series, and broad spatial extent, we need to reduce the computational burden by subsampling the data and choosing a reasonable number of spatial knots. Here, we have subsampled the data at a 10% rate, and used 150 spatial knots with which to create the spatial mesh used in the estimation. The subsampling was stratified by time and location (5°x 5° cell).

The extrapolation grid was at 2°x 2° across the spatial domain, with the exception that cells with a mean sea surface temperature of 16°C or lower were not included in the abundance predictions (Figure 10). This decision was made, due to some difficulties with the predictions for the southern most regions in 2018, and was retained in this analysis. In Region 3, low effort but relatively high catch rates were observed in some years, creating some potential biases in the model outputs. Residual analysis was performed using probability-integrated-transform (PIT) residuals (Warton et al., 2017), evaluated using the *DHARMa* R package (Hartig and Lohse, 2017).

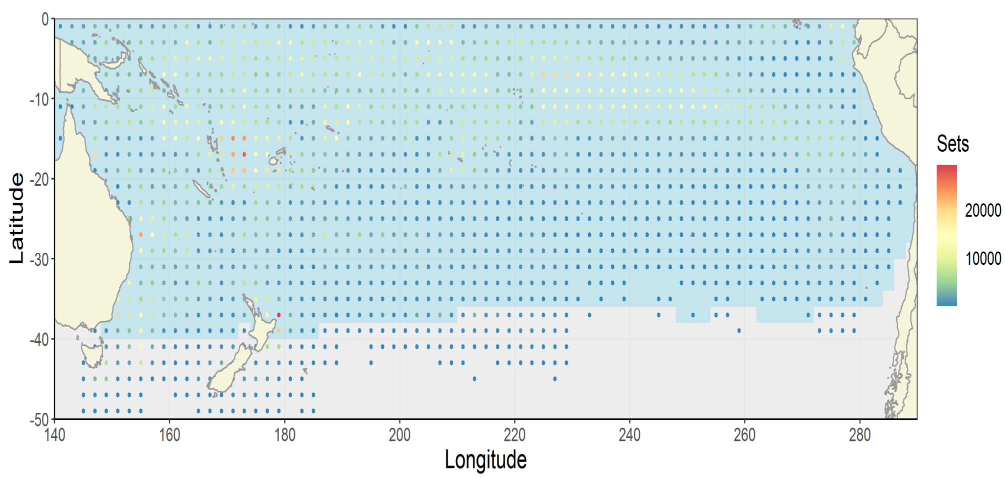

Figure 10: Map illustrating the impact of the 16°C sea surface temperature criterion for the inclusion of predictions in the abundance indices. The blue regions had a mean sea surface temperature of 16° or greater and were retained in the extrapolation grid, while the gray area was excluded.

4.3 Relative abundance indices

The model that included both flag and targeting cluster demonstrated a slightly improved fit over the model with targeting cluster as the only catchability covariate. Flag was predicted to be an important covariate as there can be fleet effects and differences in fishing strategies employed. Here, however, there was some concern around potential confounding of the abundance signal with the flag effect because there are strata where Japan is the only fleet fishing (early part of the time series and in the EPO). The main impact of the flag effect was an increase in the predicted indices in the WCPO during the early part of the time series, the time period for which Japan was the only active fleet. For much of the remaining time series, the model with and without flag predicted nearly indistinguishable index trends (Figure B.1).

In all regions, we see a decline in CPUE from the 1960s until the late 1970s, at which point the relative abundance indices are fairly stable until approximately the year 2000 (Figure 11). From 2000 to the end of the time series there is increased seasonal variability (relative to the preceding two decades) in all regions, and most pronounced in Regions 3 and 4. In Region 2, the region that supports the majority of the albacore fishery, there is a continued decline in the abundance index after the year 2000, a time period during which the abundance index remains below the time series mean. In the EPO (Region 4) there was a reduction in the seasonal variability and a decline in CPUE at the end of the time series. This signal should be interpreted with respect to the data filtering procedure. In Region 4, only data from the Japan fleet was used in the CPUE analysis, a fleet that has been only a minor contributor to removals during the most recent five years or so within that region (Figure D.1).

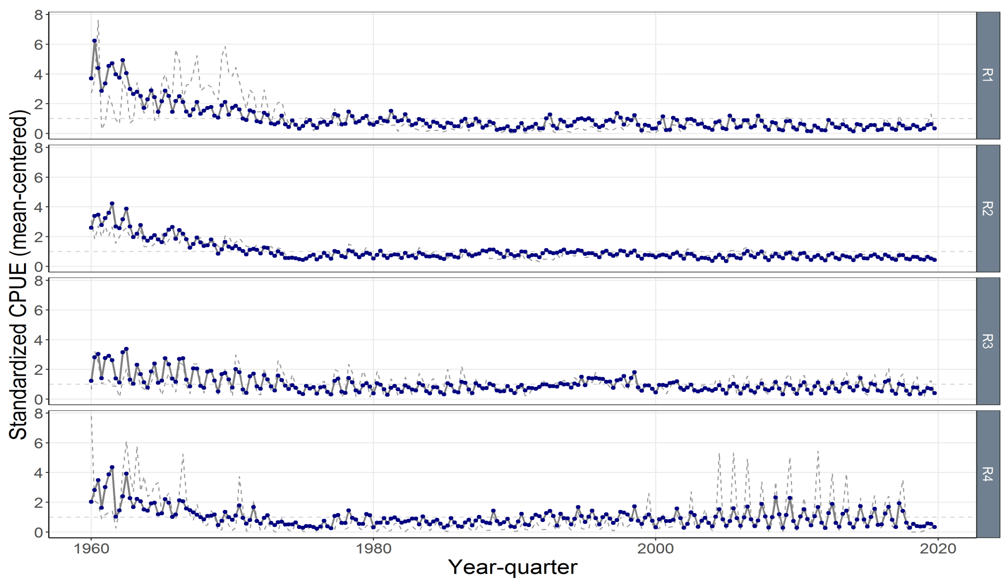

Figure 11: Standardized relative abundance indices, by region (gray with blue points) plotted alongside the nominal CPUE (gray dashed line), from 1960-2019.

The model was robust to the subsampling routine, showing minimal differences based on the randomly sampled data set. The PIT residuals, aggregated across the time series, at the level of the knot, exhibited a normal distribution centered around 0.5, indicating an overall reasonable fit to the data. There was however, a notable spatial pattern in the residuals, such that the main albacore fishing grounds generally exhibited residuals above 0.5, and the peripheral areas generally exhibited residuals below 0.5 (Figure 12). This pattern suggests that, in general, relative abundance estimates may be slightly underestimated in the main albacore regions and overestimated in the peripheral regions.

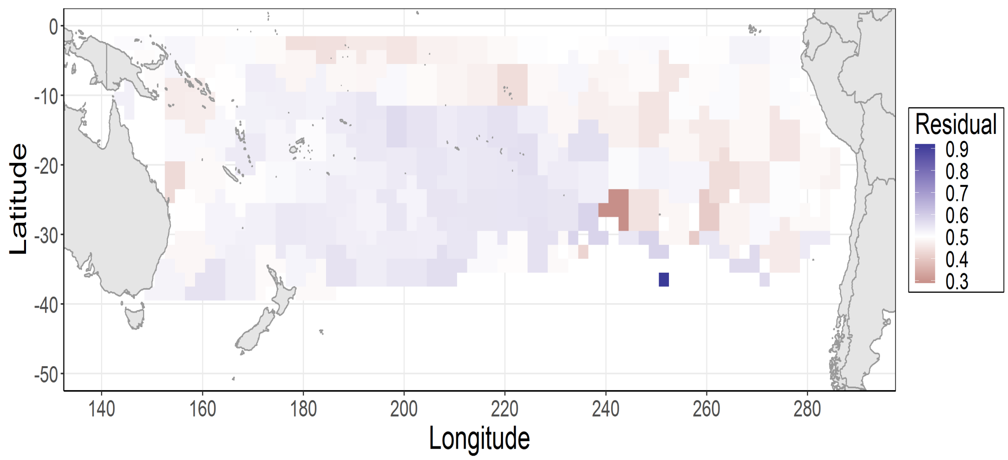

Figure 12: Spatial distribution of PIT residuals aggregated across the full time series, at the level of the knot.

The influence of the catchability covariates was evaluated (Bentley et al., 2012) with flag showing a notable increasing trend over the time series, while the influence of targeting cluster was more nonlinear and variable by region (Figure 13). The increase in the influence of flag suggests that by omitting this variable from the standardization mode, the index would be lower in the early part of the time series and higher towards the end. The targeting cluster influence is fairly neutral for Regions 2 and 3, although with a substantial regional pattern in Region 3. Regions 1 and 4 indicate the index would be higher in the early and later parts of the time series, these patterns are likely associated with the changes in targeting yellowfin or bigeye versus albacore.

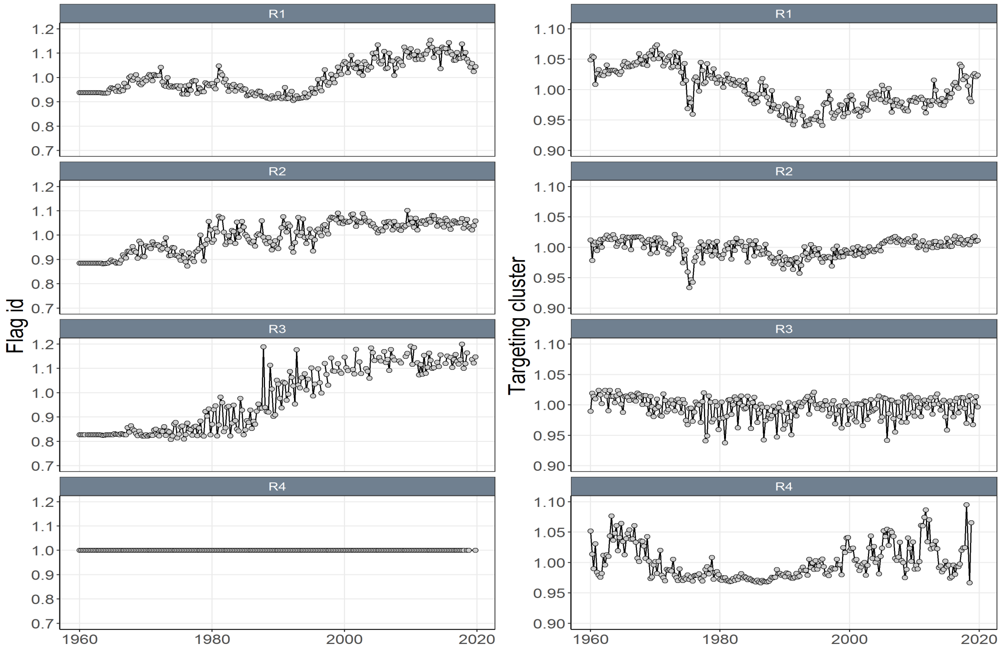

Figure 13: Influence of the catchability covariates (flag on the left; targeting cluster on the right) on the relative abundance indices, by region. The influence of flag in Region 4 is flat because Japan was the only fleet included for that region, hence the flag influence is constant over the time series.

4.4 Spatial and spatiotemporal variability

The spatial effects for both encounter probability and positive catch rates for albacore clearly illustrate a strong gradient in space, such that below 10°S the probability of encounter is higher than along the equatorial regions (Figure 14). Similarly, positive catch rates are generally higher from 10°S in the central and western Pacific. In the EPO there is a region of relatively high positive catch rates around 15°S, but generally relative catch rates are lower in the EPO. These patterns may be driven in part due to targeting behaviors that have not been sufficient characterized in the model, as in the EPO, bigeye targeting was more common throughout much of the time series, and only since the mid to late 1990s has there been more intentional targeting of albacore. In addition, the spatiotemporal variability ϕ was higher than the static spatial variability ω for both encounter probability (σ_ω = 0.45; σ_ϕ = 1.95) as well as the positive catch rate component (σ_ω = 0.79; σ_ϕ = 1.78).

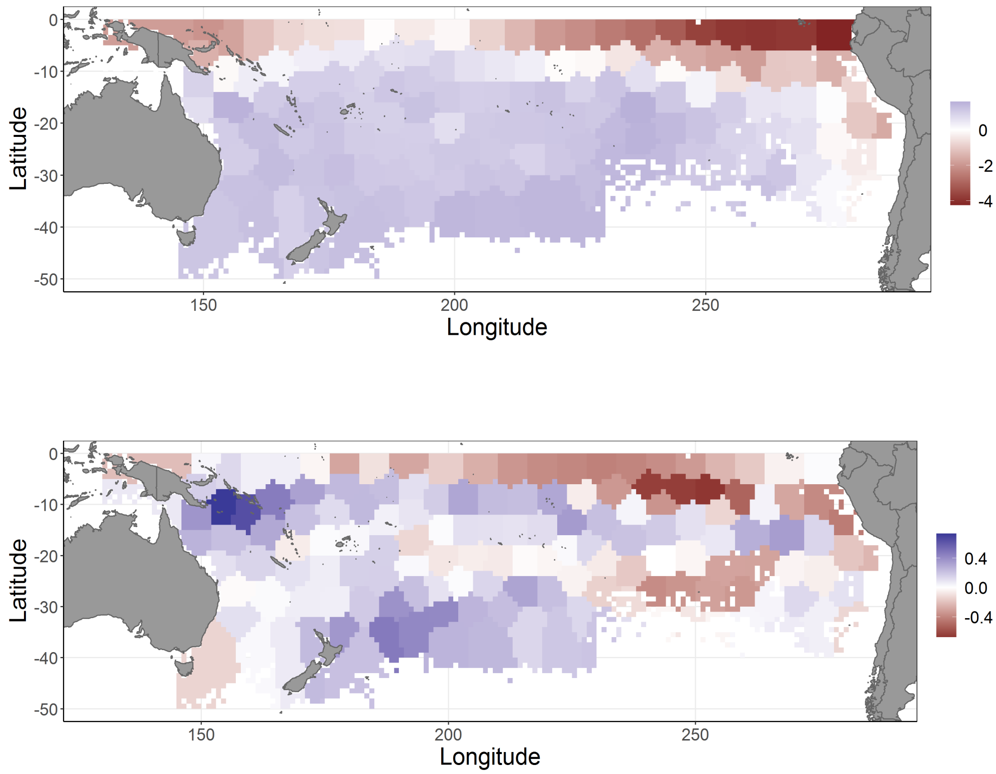

Figure 14: Spatial effects associated with the first (top) and second (bottom) linear predictors from the standardization model, relating to encounter probability and positive catch rates, respectively.

4.5 Future considerations

The development of relative abundance indices for the South Pacific albacore longline fishery benefits from a long and comprehensive time series of catch and effort in the region. However, this time series is largely lacking specific vessel and gear information (specifically for the historical time period) as well as detailed information on targeting practices and fishing strategy. To better inform the albacore assessments moving forward, attention needs to be given to enhancing data collection from this fishery. The observer program collects additional data elements which would be valuable for standardization, but as of now the coverage rates are far too low to provide the spatial and temporal coverage needed for such an analysis. In addition to observer coverage, the advancement of electronic monitoring programs should be prioritized to enhance the availability of data with which to monitor and assess this stock.

5 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.

5.1 Methods

Albacore length samples from longline fisheries were extracted from SPC's LF MASTER database, along with aggregate longline catch data from SPC's L BEST database. Albacore length 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 length samples and aggregate catch data were also aggregated to a year-quarter temporal resolution to match the structure of the assessment model.

The procedure used to reweight the size compositions was based on that used to prepare bigeye and yellowfin size compositions for the 2020 assessments (Peatman et al., 2020), which itself was developed from the approach of McKechnie (2014) and Tremblay-Boyer et al. (2018b) for regular and index fisheries respectively.

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, length samples were aggregated to a 10 x 20° and region spatial resolution as follows:

- All length samples were split to a 5° spatial resolution using the proportion of reported catches 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.
- 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.
- The length 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 length compositions were then reweighted spatially by fishery in the assessment model, using the following approach:

- For a given fishery, length samples and aggregate catches (numbers) were aggregated to a stratification of year-quarter and 10 x 20° cell.
- Length data from strata with fewer than 30 samples were excluded.
- 'Strata weights' for regular fisheries 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. Strata weights for index fisheries were equivalent but weighted by estimated relative abundance from the CPUE standardisation model by 10 x 20° cell and year-quarter, rather than catch.
- Strata-level numbers by length-class were then converted to proportions by length-class.
- Strata-level proportions by length-class were then weighted by multiplying by the appropriate strata weight $W_{i,t}$.
- The weighted proportions by length-class were then summed across strata to obtain proportions by length-class and year-quarter for the fishery.
- The fishery-resolution proportions by length-class were then raised to numbers by length-class, by multiplying by the total number of length samples for the fishery and year-quarter.

This approach implicitly scales the effective sample size at a fishery and year-quarter resolution by the proportion of catch (regular fisheries) or relative abundance (index fisheries) accounted for by 10 x 20° cells with length samples. For example, if sampled 10 x 20° cells accounted for 75% of the total catch for a fishery and year-quarter, then the effective sample size would be equal to 75% of the total sample size for that year-quarter.

The fishery-resolution length compositions were then filtered for year-quarters where sampled 10 x 20° cells accounted for a minimum proportion of the total catch of the fishery (regular fishery) or the total relative abundance in the corresponding assessment model region (index fisheries), i.e. filtering for year-quarters where the sum of strata weights from sampled 10 x 20° cells exceeded a specified threshold. These minimum proportions are referred to throughout as the 'minimum sampled weighting'.

Effective samples were then rescaled appropriately for use with the different likelihood components used to model size compositions in MFCL, i.e. the robust-normal likelihood, and the self-scaling multinomial (SSM) likelihood. As described above, the reweighting procedure decreases effective sample sizes using the proportion of total catch (extraction fisheries) or abundance (index fisheries) from strata with length samples. Effective sample sizes for the robust-normal likelihood were then set at 50% of the down-weighted effective sample size, to account for the use of the same length samples when generating length compositions for both index and regular fisheries. The effective sample sizes for the robust-normal likelihood are then commonly scaled down further within MFCL as part of the model fitting process, typically by a factor in the range of 10 to 200. Effective sample sizes for the self-scaling multinomial likelihood were set at the original sample size, and again reduced by 50% as per sample sizes for the robust-normal likelihood. It is important to note that, whilst the effective sample sizes for the robust-normal and self-scaling multinomial can (and often do) differ, the length compositions in proportional terms are the same.

The reweighting approach is equivalent to that used for the 2015 and 2018 assessments (Scott and McKechnie, 2015; Tremblay-Boyer et al., 2018b), apart from differing approaches to data filtering. Here, we excluded size composition data for a specific fishery and year-quarter if sampled strata did not account for a minimum proportion of fishery catch (regular fisheries) or relative abundance (index fisheries). This excludes length compositions at a fishery-level for year-quarters where available length samples may not be representative of the fishery. In contrast, the 2015 and 2018 assessments implemented data filtering at a strata-level, keeping only data from strata which accounted for a minimum proportion of catch (regular fisheries) or relative abundance (index fisheries) for a particular fishery and year-quarter. Both approaches aim to reduce unwanted temporal variation in size compositions resulting from changes in sampling coverage through time. However, the strata-level approach to data filtering was considered less appropriate for use in this assessment, given the large variation in strata between fisheries and a preference for using a consistent threshold for all fisheries.

Approximately 95% of available albacore length samples in subareas 4b and 4c were from Japanese longline vessels. However, the vast majority of the Japanese length samples in subareas 4b and 4c were provided at a 2cm resolution from 2006 onwards. In order to maximise the available time-series of size compositions in these subareas, whilst maintaining a 1cm length class, the 2cm data were split 50:50 to a 1cm resolution.

In initial reweighting runs, variability in length compositions increased in the 2010s for the index fishery in region 4, with the introduction of length samples from non-Japanese flag fleets. This variation was driven by apparent differences in size compositions between flag-fleets, as well as within flag-fleet variability in some cases, and was considered unlikely to reflect changes in size compositions of the underlying population. In order to remove this temporal variation, it was decided to use only length samples from the Japanese-flagged vessels for the index fisheries in region 4.

Analyses of length compositions were undertaken to inform the fisheries structure for region 4 (Appendix E). These analyses identified spatial structure in length compositions, with larger albacore caught in subarea 4a relative to catches in subareas 4b and 4c. This spatial structure in length compositions, coupled with seasonality in the availability of length samples by subareas, introduced temporal variation in exploratory reweighted length compositions for region 4 when including data from all subareas. As such, we prepared two options for index fisheries for region 4. The first option had one index fishery, using length samples from subarea 4a only, reweighted with estimated relative abundance in subarea 4a. The second option had two index fisheries, the index fishery for subarea 4a (from the first option), plus another index fishery using length samples from subarea 4b and 4c; however this option was not used in the final models.

Tremblay-Boyer et al. (2018b) used a time-window of 11 quarters (k = 5) for calculation of strata weights for regular longline fisheries. Visual examination indicated that reweighted compositions were insensitive to the length of the time-window, and so we kept a time-window of 11 quarters for all extraction fisheries. We used a time-window of 1 quarter (k = 0) for index fisheries, in order to prevent excessive smoothing of seasonality in albacore distributions within regions when calculating strata weights. However, we note that reweighted index fishery compositions were similarly insensitive to the length of time-window for strata weights.

5.2 Results

Reweighted size compositions for extraction fisheries are provided in Figures 15–20, with index fishery compositions provided in Figures 21 and 22. Size compositions exhibited reasonably strong apparent noise in some cases (e.g. index fishery compositions for region 2 - Figure 21). This was commonly associated with year-quarters with relatively low numbers of samples, either due to seasonality in the underlying fishery (e.g. fisheries in region 3), or limited availability and/or coverage of samples, and as such the noise should have limited influence on the assessment model.

The choice of minimum sampled weighting is a compromise between attempting to remove temporal variation in sizes as a result of limited and unbalanced sampling, whilst attempting to minimise filtering of size compositions and so preserve temporal coverage of reweighted compositions (e.g. McKechnie, 2014). Peatman et al. (2020) recommended a threshold of 0.3 and 0.1 for extraction and index fisheries respectively for the 2020 bigeye and yellowfin assessments. Comparison of different thresholds suggested that 0.3 and 0.1 were also appropriate here for regular and index fisheries, and so are recommended for the 2021 South Pacific albacore assessment. We recommend assessing the sensitivity of the assessment model to the minimum sampled weighting threshold, given that the selection of the threshold is subjective and somewhat arbitrary. Thresholds of 0.7 and 0.3 would be appropriate for extraction and index fisheries respectively for assessing sensitivity of the model to stronger data filtering.

Spatial stratification was used to reweight length compositions for both extraction and index fisheries, i.e. strata were defined as combinations of 10 x 20° cell and year-quarter. This accounts for spatial variation in size compositions within a region, 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 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. We also note that, for extraction fisheries, stratification by flag-fleet gave comparable compositions to spatial stratification.

Reweighted compositions for the PICT fisheries in region 1 and region 2 had persistent increases in proportions at approximately 90cm (Figure 17). Comparisons of length compositions between data-sources were undertaken, to explore potential drivers for the pattern. The pattern was apparent in length compositions for a number of flag-fleets, and featured in length samples originating from both observers and port-sampling. As such, it was considered unlikely to reflect bias in sampling, for example due to reduced availability of small individuals during port-sampling.

There is apparent 2cm, and in more limited cases 5cm, resolution length data recorded as 1cm resolution in LF Master (e.g. see reweighted compositions for distant water fishing nation fishery in region 2, Figure 15). Targeted investigation suggested that it would not be possible to exclude 2cm data, without also excluding data with 1cm length-classes, given the resolution of raw data in LF Master. Increasing the length-classes to 2cm intervals would be the most practical way of addressing this, and would also remove the need to disaggregate 2cm samples from Japanese longliners in region 4.

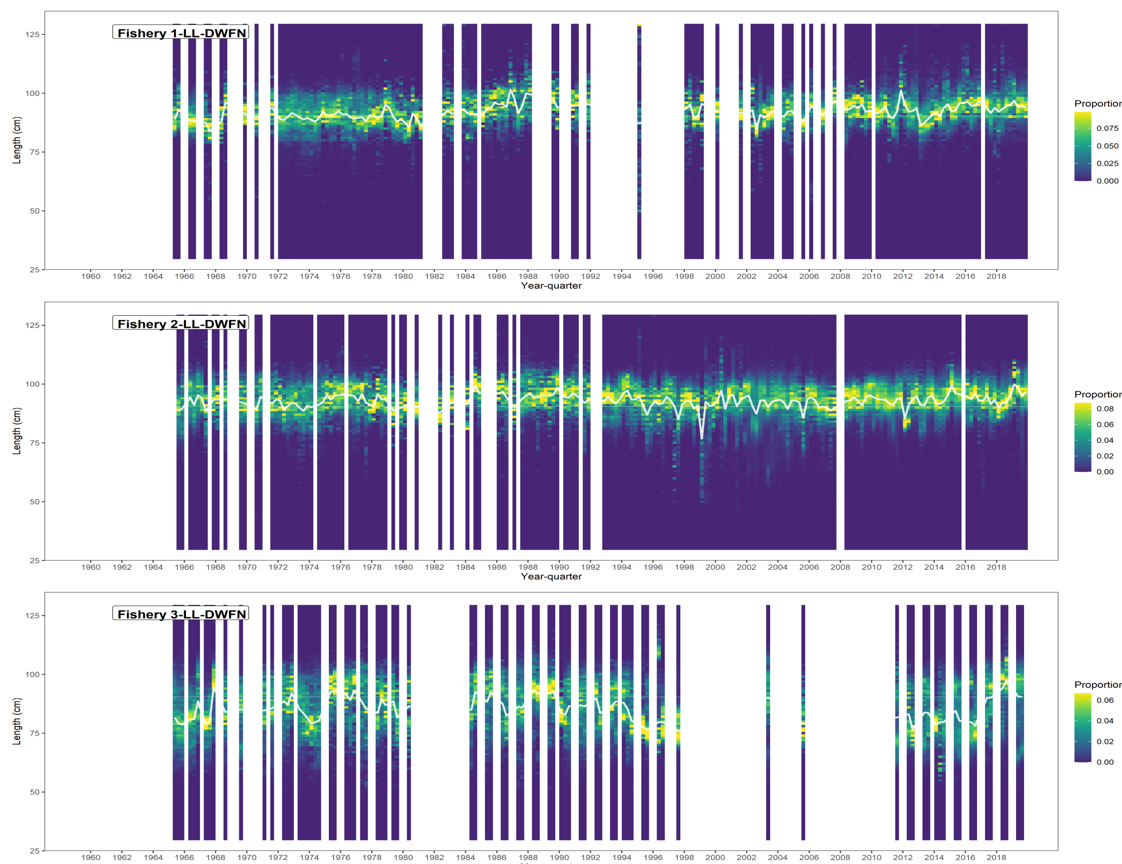

Figure 15: Reweighted length compositions for distant water fishing nation (DWFN) extraction fisheries in regions 1 (top panel), 2 and 3 (bottom panel). Note these fisheries do not include the area overlapping WCPFC and IATTC Convention Areas. A minimum sampled weighting of 0.3 was applied. The white line provides the median size by year-quarter.

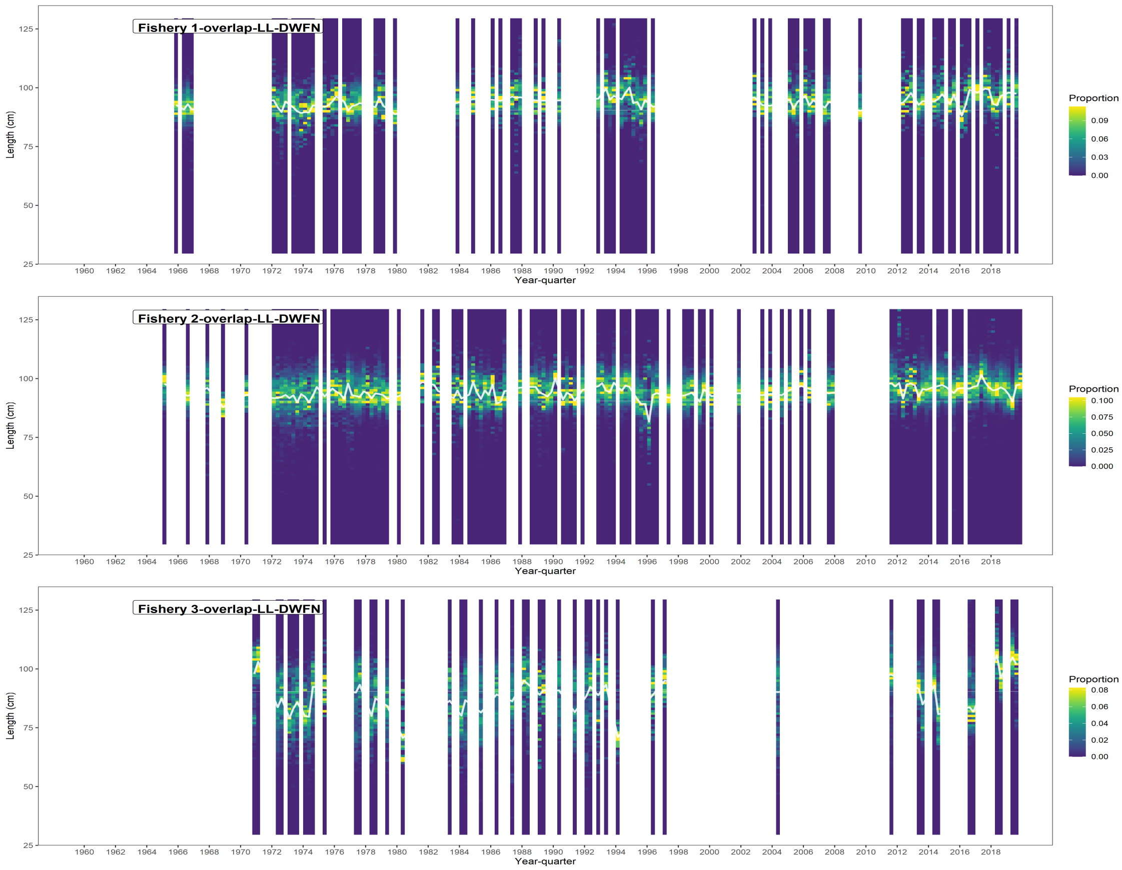

Figure 16: Reweighted length compositions for distant water fishing nation (DWFN) extraction 'overlap' fisheries in regions 1 (top panel), 2 and 3 (bottom panel), i.e. in the area overlapping WCPFC and IATTC Convention Areas. A minimum sampled weighting of 0.3 was applied. The white line provides the median size by year-quarter.

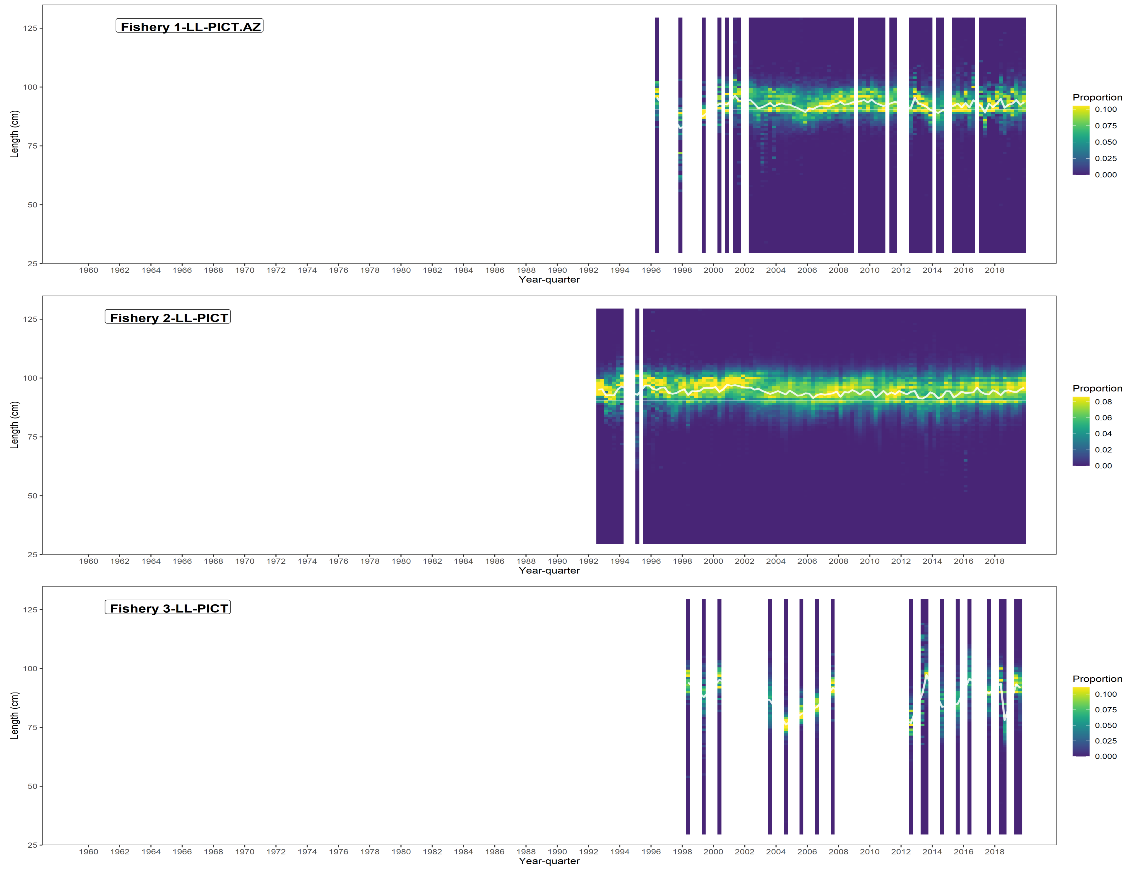

Figure 17: Reweighted length compositions for Pacific Island Country and Territory (PICT) extraction fisheries in regions 1, 2 and 3. Note these fisheries do not include the area overlapping WCPFC and IATTC Convention Areas. A minimum sampled weighting of 0.3 was applied. The white line provides the median size by year-quarter.

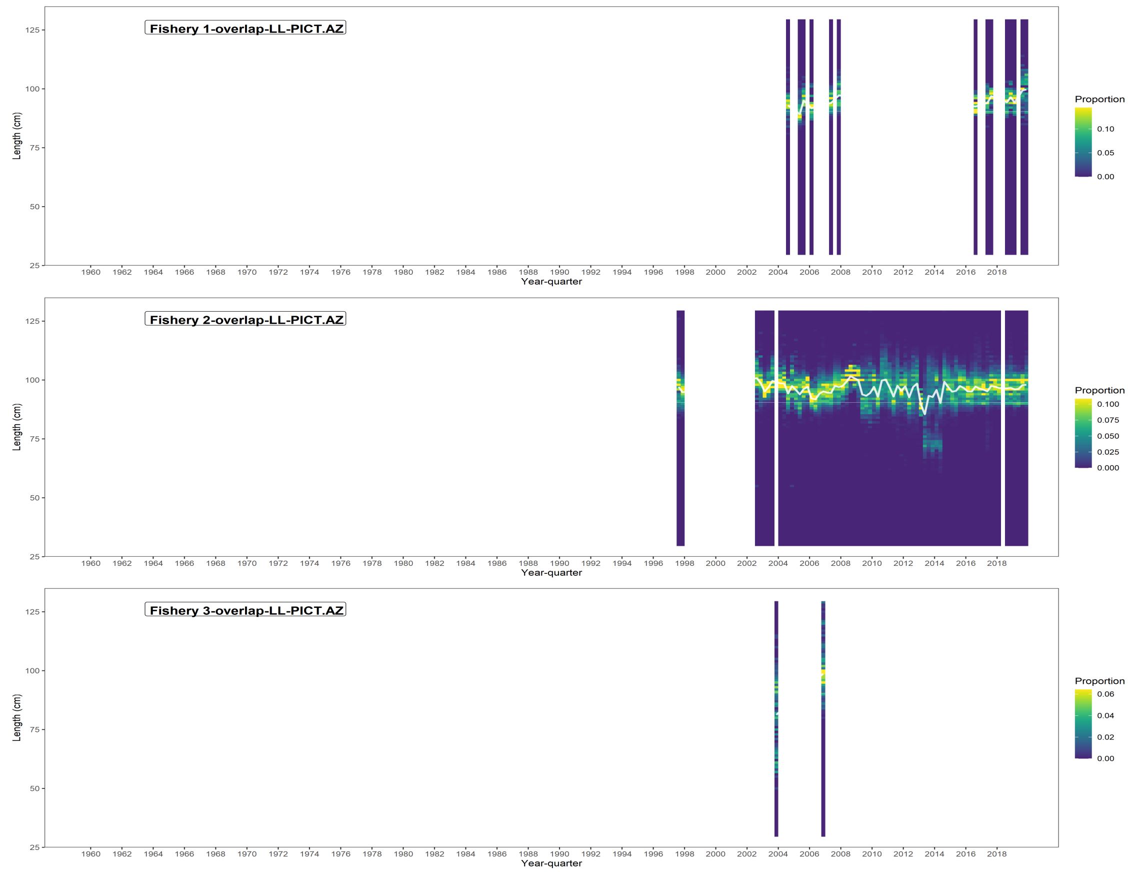

Figure 18: Reweighted length compositions for Pacific Island Country and Territory (PICT) extraction 'overlap' fisheries in regions 1 (top panel), 2 and 3 (bottom panel), i.e. in the area overlapping WCPFC and IATTC Convention Areas. A minimum sampled weighting of 0.3 was applied. The white line provides the median size by year-quarter.

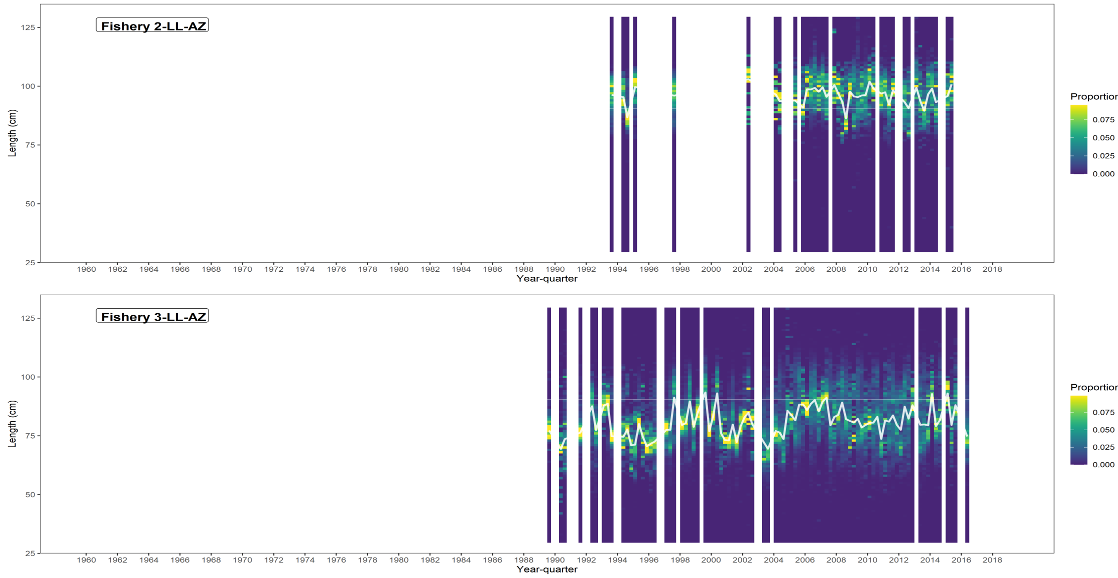

Figure 19: Reweighted length compositions for the Australia and New Zealand extraction fisheries in regions 2 (top panel) and 3 (bottom panel). Note these fisheries do not include the area overlapping WCPFC and IATTC Convention Areas. A minimum sampled weighting of 0.3 was applied. The white line provides the median size by year-quarter.

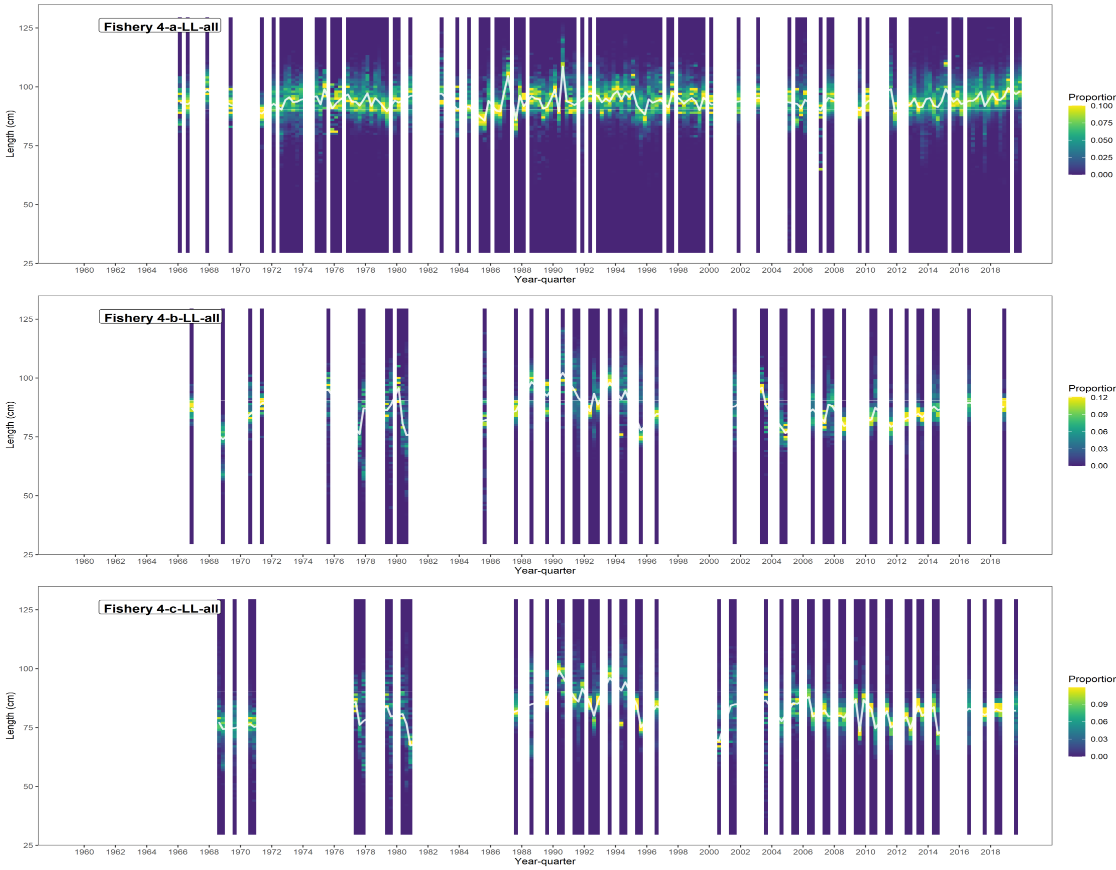

Figure 20: Reweighted length compositions for extraction fisheries in region 4 subarea a (top panel), subarea b, and subarea c (bottom panel). A minimum sampled weighting of 0.3 was applied. The white line provides the median size by year-quarter.

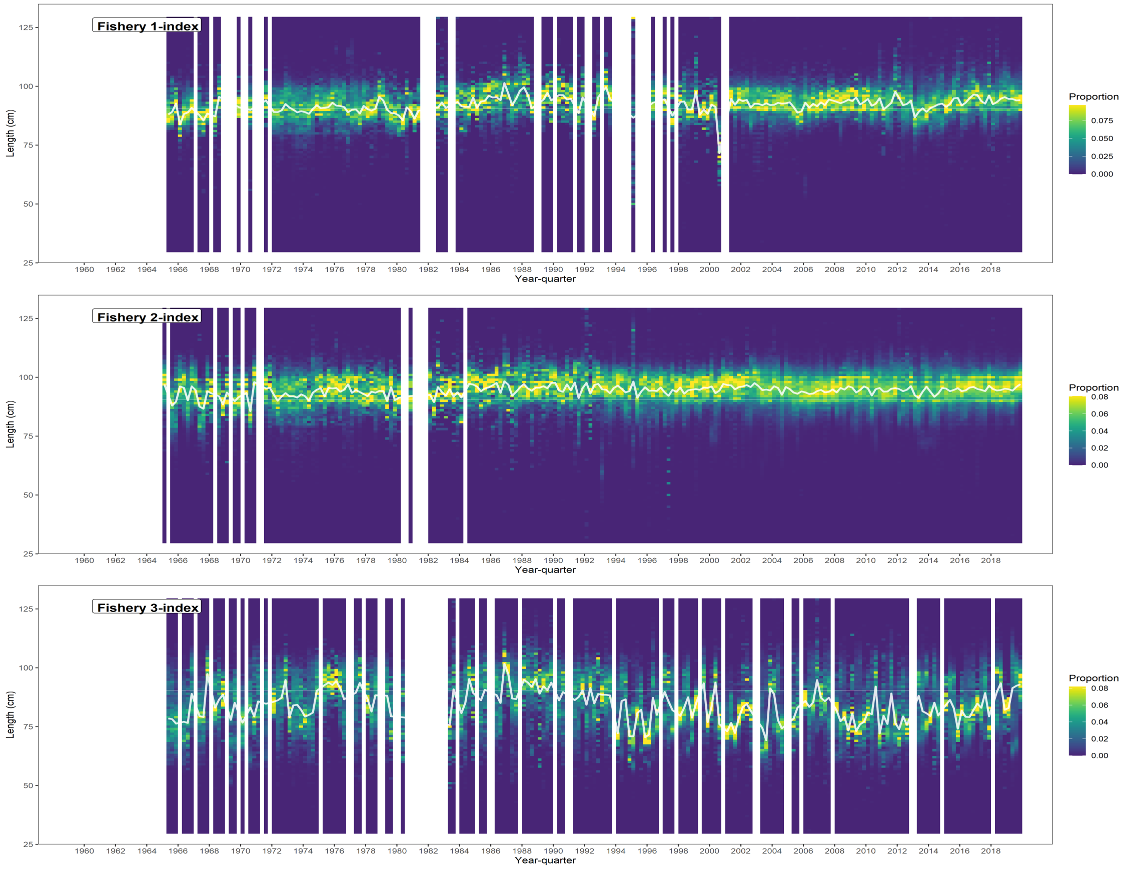

Figure 21: Reweighted index fishery compositions for regions 1 (top panel) to 3 (bottom panel). A minimum sampled weighting of 0.1 was applied. The white line provides the median size by year-quarter.

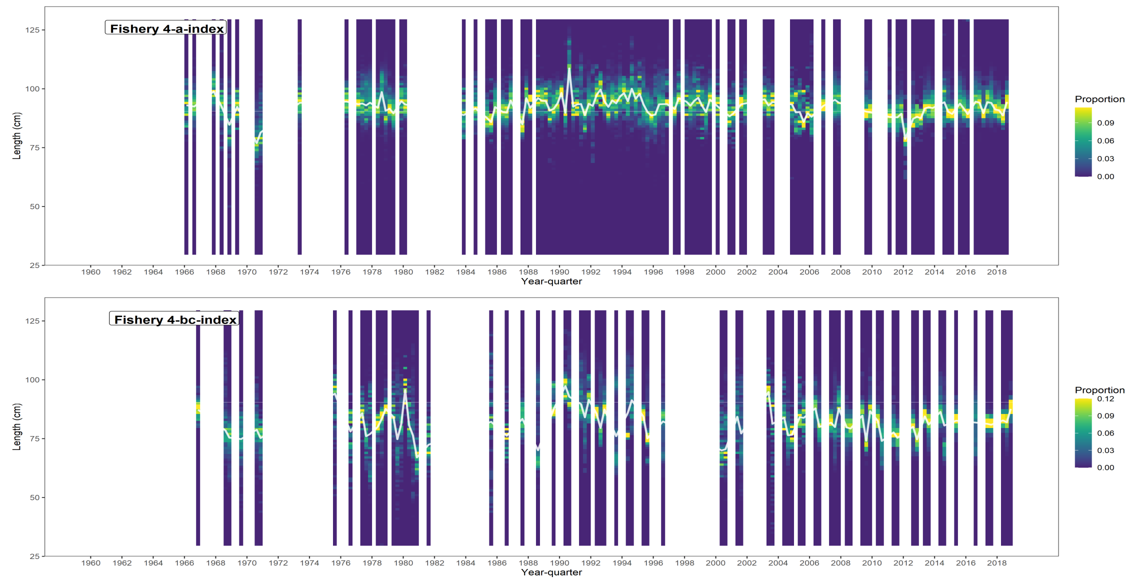

Figure 22: Reweighted index fishery compositions for regions 4, using data from subarea 4a (top panel), and data from subareas 4b and 4c (bottom panel). A minimum sampled weighting of 0.1 was applied. The white line provides the median size by year-quarter.

6 Regional weights

The same CPUE standardization model was used to derive regional weights. Regional weights were calculated using the area-weighted sum of all the predicted cell abundances, scaled across assessment regions to sum to 1 across the period 1975-2019, during which the data had better coverage. Only cells with a mean SST of 16° C or greater more were included as part of the abundance predictions for the southernmost regions (i.e. in the extrapolation grid). The colder regions had very little effort yet were predicted to have very high abundance based on the high observed CPUE. There were no observations to confirm whether those predicted abundances were indeed realistic, but it was assumed that the lack of fishing effort in that part of the assessment region throughout the time-span of the assessment likely indicated that local catch rates were in fact low.

Initial model development for 2021 in the step-wise procedure involves comparison of the 2018 modeling approach with updated data. The updated regional indices from the 2018 model structure demonstrated notable departures from the original 2018 trends (Tremblay-Boyer et al., 2018b). These differences are likely due to the impact of updates to historical data. All runs within the structural uncertainty grid, used the same regional weights from the preferred standardization model.

7 Tagging data inputs

Tagging data for the 2021 stock assessment consisted of tag releases and returns from a South Pacific Albacore Research Group tagging programme in the mid-1980s and SPC albacore tagging programmes conducted during the austral summers of 1990-1992 and 2009-2010 (see Hoyle et al., 2012 for additional detail). Albacore were captured primarily by trolling and tagged using standard tuna tagging equipment and techniques by trained scientists and scientific observers. During the 1980s and 1990s, the majority of tag releases were made by scientific observers on-board New Zealand and US troll vessels fishing in New Zealand waters and in the central South Pacific subtropical convergence zone region. The more recent tagging was conducted in New Zealand waters.

The construction of the tagging files (hereafter .tag files) for use in MFCL for the 2021 assessment follows very closely the recent methodology used for skipjack (McKechnie et al., 2016), and bigeye and yellowfin tuna (McKechnie et al., 2017). The raw .tag data files constructed from SPC databases underestimate recapture rates of tagged fish due to: not all recaptured tags being usable in MFCL (e.g. tags without recapture dates, location or vessel identification often cannot be attributed to a model fishery and are therefore excluded from the stock assessment); some fish shed tags immediately, or some time after tagging; and some tagging-induced mortality occurs such that tagged fish assumed to be present in the population will have already died. This results in fishing mortality being underestimated by this data component, which will potentially lead to underestimates of biomass.

The methodology of correcting releases and filtering of the data for input into MFCL is covered in detail by McKechnie et al. (2017), and so we provide only the following brief overview of the process and refer readers to that study for relevant details, especially the formulae used to correct release numbers which are presented in Section 3.4 of that report. The concise details of the methodology used to construct the .tag file are:

- The 'raw' .tag file for MFCL is produced using software written in FoxPro and only includes usable tags (those that can be assigned to a fishery and time period).
- A parallel programme written in the R statistical language (R Core Team, 2020) uses identical SQL queries with the exception that it extracts all recaptures (usable and unusable) and produces a 'full' .tag file.
- The usability ratio is calculated as the ratio of usable to total recaptures at the scale of the length bin within a tagging release event.
- The number of releases is then scaled down by these release-group- and length bin-specific correction ratios.

We retained the tag adjustment used in 2018, by adjusting the tag release numbers downwards by a factor of 0.5 to account for likely mortality of albacore due to the stress of capture, handling and tagging. Initial tagging mortality operates in a similar fashion to non-reporting and was therefore dealt with by adjusting the releases. The choice of 0.5 as the adjustment factor was somewhat arbitrary, but was influenced by previous work on tagger effects on tagged fish survival and associated correction factors in what are thought to be more robust tropical tunas (Berger et al., 2014). In that study it was found that the median correction factors for tagger effects were 0.68-0.76 for the tropical tunas. Given that albacore are believed to be more sensitive to capture and handling, it was felt that a stronger correction was appropriate in this case. Sensitivity was tested in a previous assessment, within minimal impacts (Harley et al., 2015).

In contrast to the tropical tuna stocks in the WCPO, no information on tag reporting rates in the form of tag seeding trials were available for South Pacific albacore. This prevented the construction of informative tag reporting rate priors, and so uninformative, diffuse priors with a mean of 0.1 were used for all reporting rate groupings.

Note that there were no additional tag releases subsequent to the 2018 assessment.

8 Maturity-at-length

The maturity function is routinely input to stock assessment models as a fixed vector of age-specific values as there is very little information to inform the model of its shape. MULTIFAN-CL allows the user to input length-based spawning potential, which is then converted internally within the model to an age-based vector dependent upon the growth.

We specified spawning potential-at-length as the product of sex ratio and maturity-at-length, rescaled to 1. Sex ratio at length was obtained by fitting a spline to observed sex-ratio from SPC-held longline observer data, stratified by flag and 10° cell and weighted by longline catch to account for uneven observer coverage amongst fleets in space. Longline observer data only covered lengths from 70 to 110cm so we extrapolated to cover the stock assessment range by (1) setting sex ratio for lengths $<$ 70cm at the 70cm value and (2) assuming sex ratio for females declined linearly from the value observed at 110cm to 0 at 130cm. The maturity proportion at length was obtained from the weighted maturity ogives presented in Farley et al. (2014), smoothed via a logistic curve. The final input to MULTIFAN-CL was a product of those two ogives, rescaled so that the maximum was 1.

9 Acknowledgments

We are grateful to the member countries for committing to sharing their operational-level catch and effort data, which are invaluable for these analyses. T. Vidal and T. Peatman's contributions were supported by the European Union's "Pacific-European Union Marine Partnership Programme". We thank Graham Pilling for comments and edits on an earlier version. We thank all the onboard observers, skippers and port samplers for their contributions to data collections over many years, and the OFP-FEMA team for their ongoing work in improving understanding of albacore biology and stock structure. Finally, we thank Sam McKechnie for providing his infinite wisdom on all things South Pacific albacore.

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Appendix

A Catch and length frequency trends by fishery

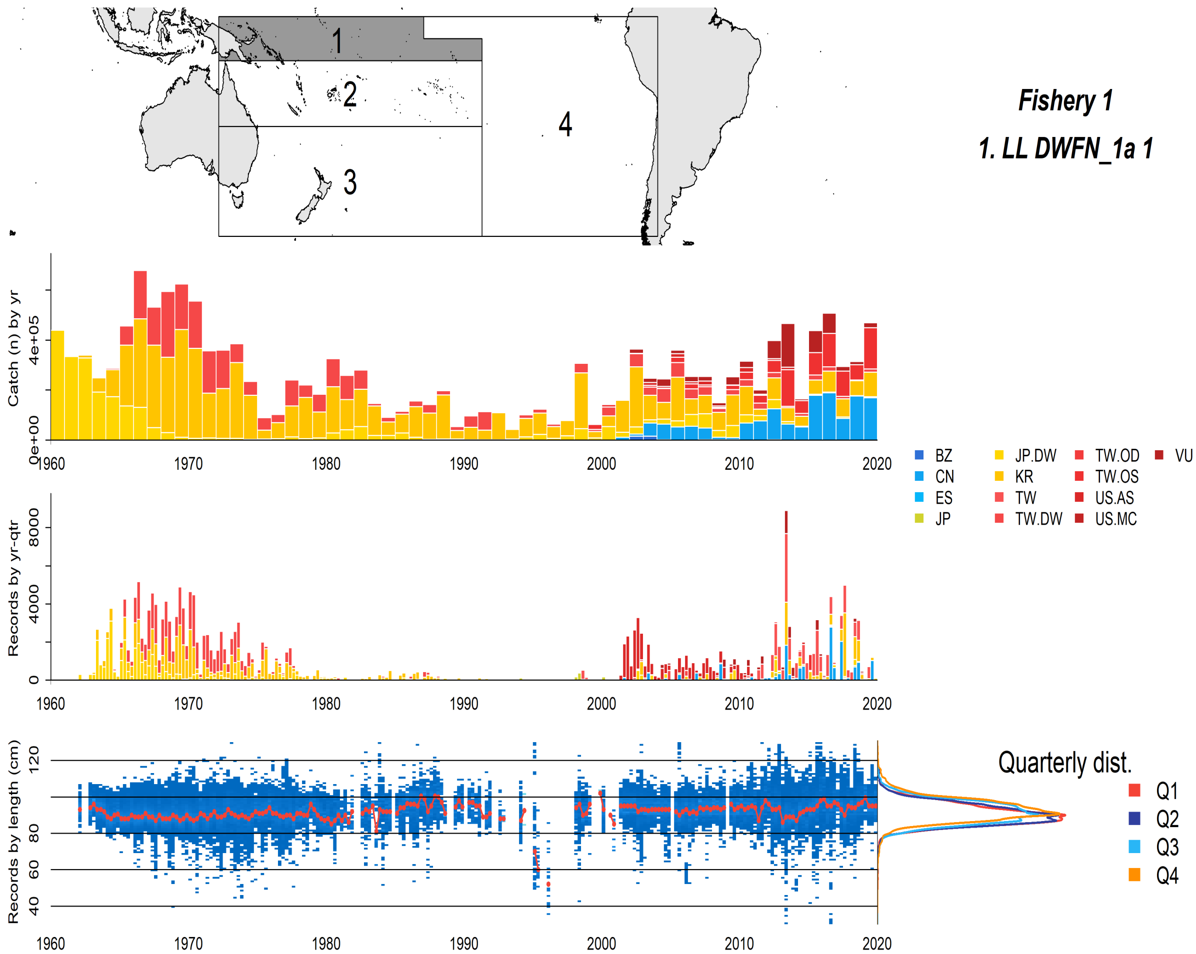

Figure A.1: Summary of raw data available for fishery 1 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

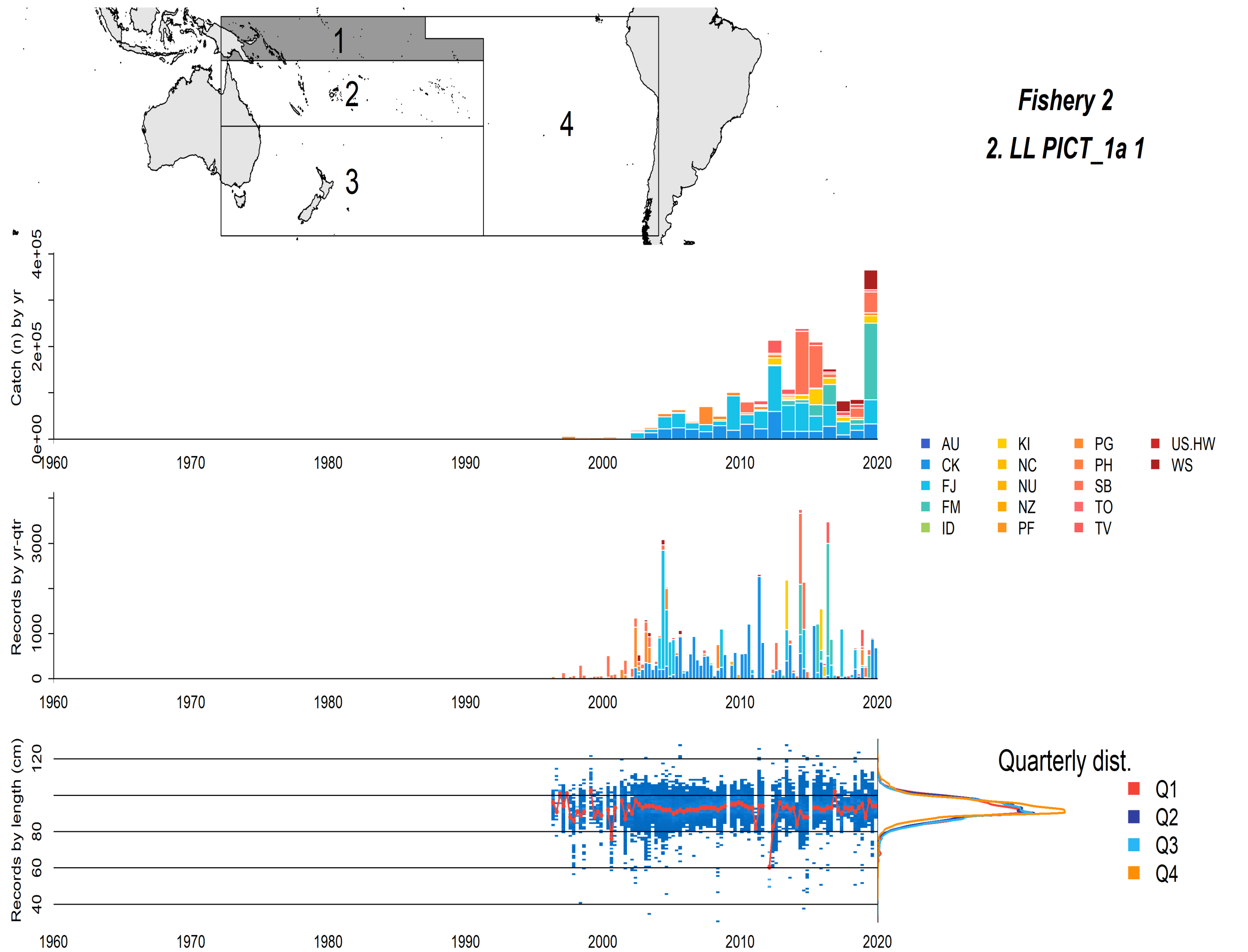

Figure A.2: Summary of raw data available for fishery 2 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

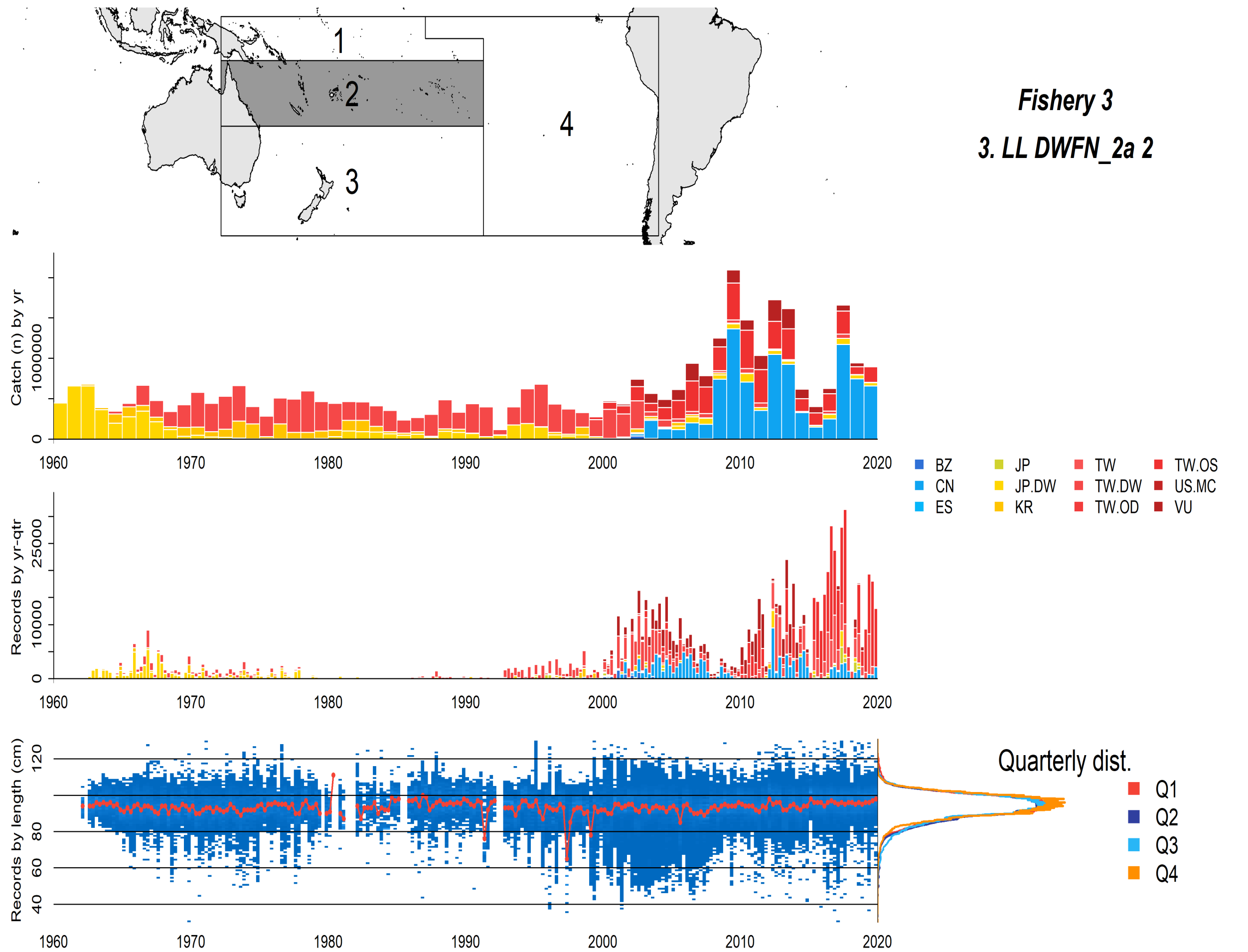

Figure A.3: Summary of raw data available for fishery 3 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

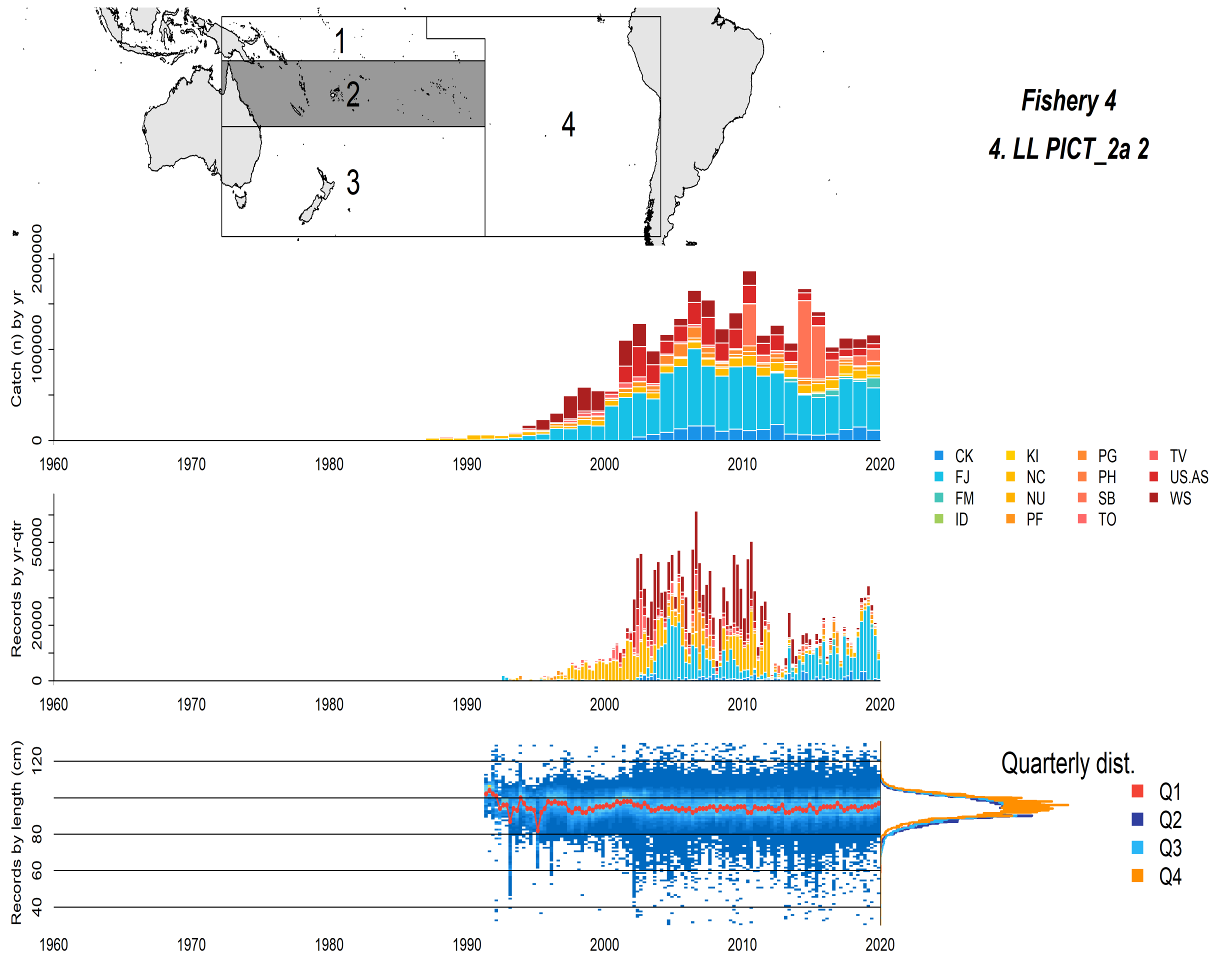

Figure A.4: Summary of raw data available for fishery 4 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

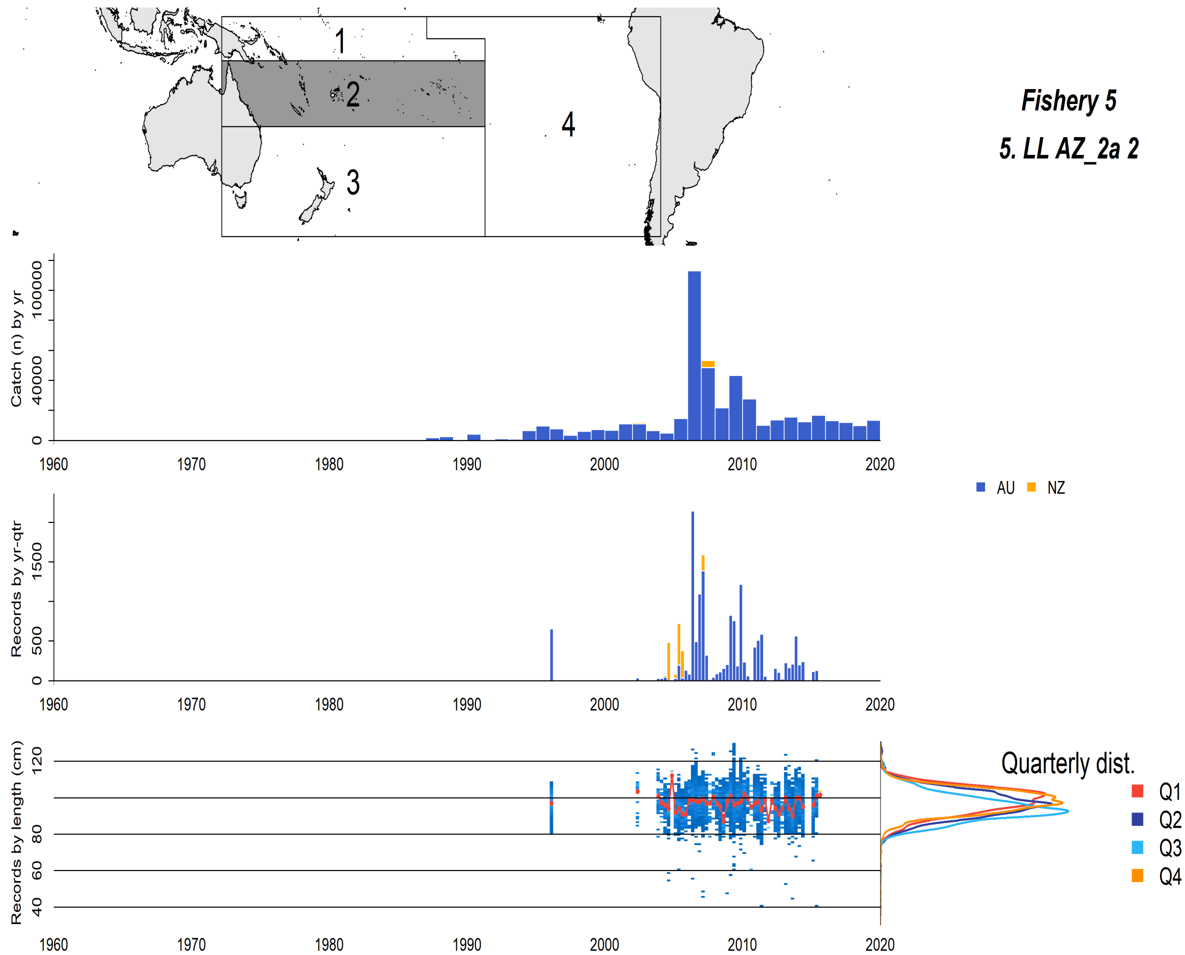

Figure A.5: Summary of raw data available for fishery 5 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

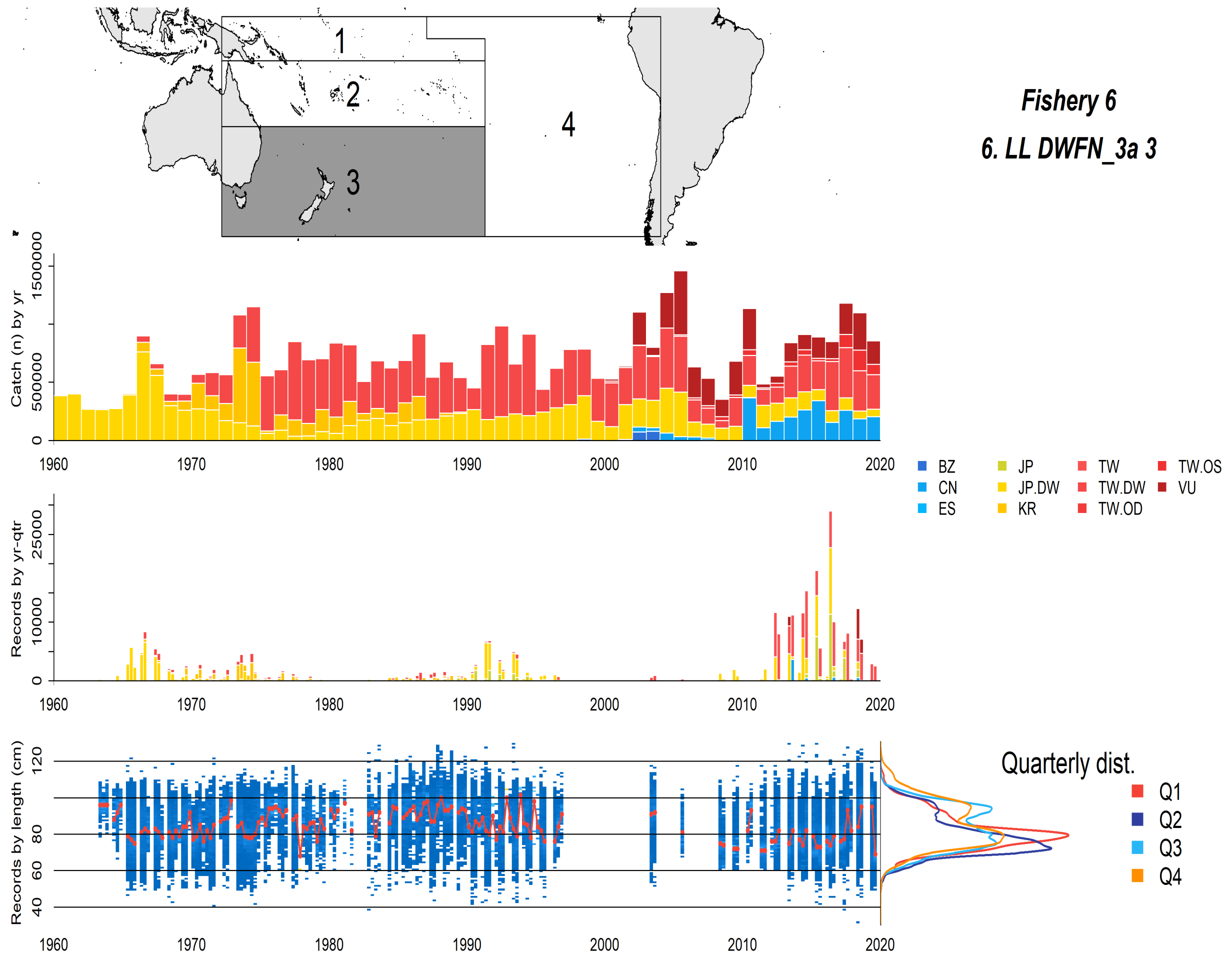

Figure A.6: Summary of raw data available for fishery 6 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

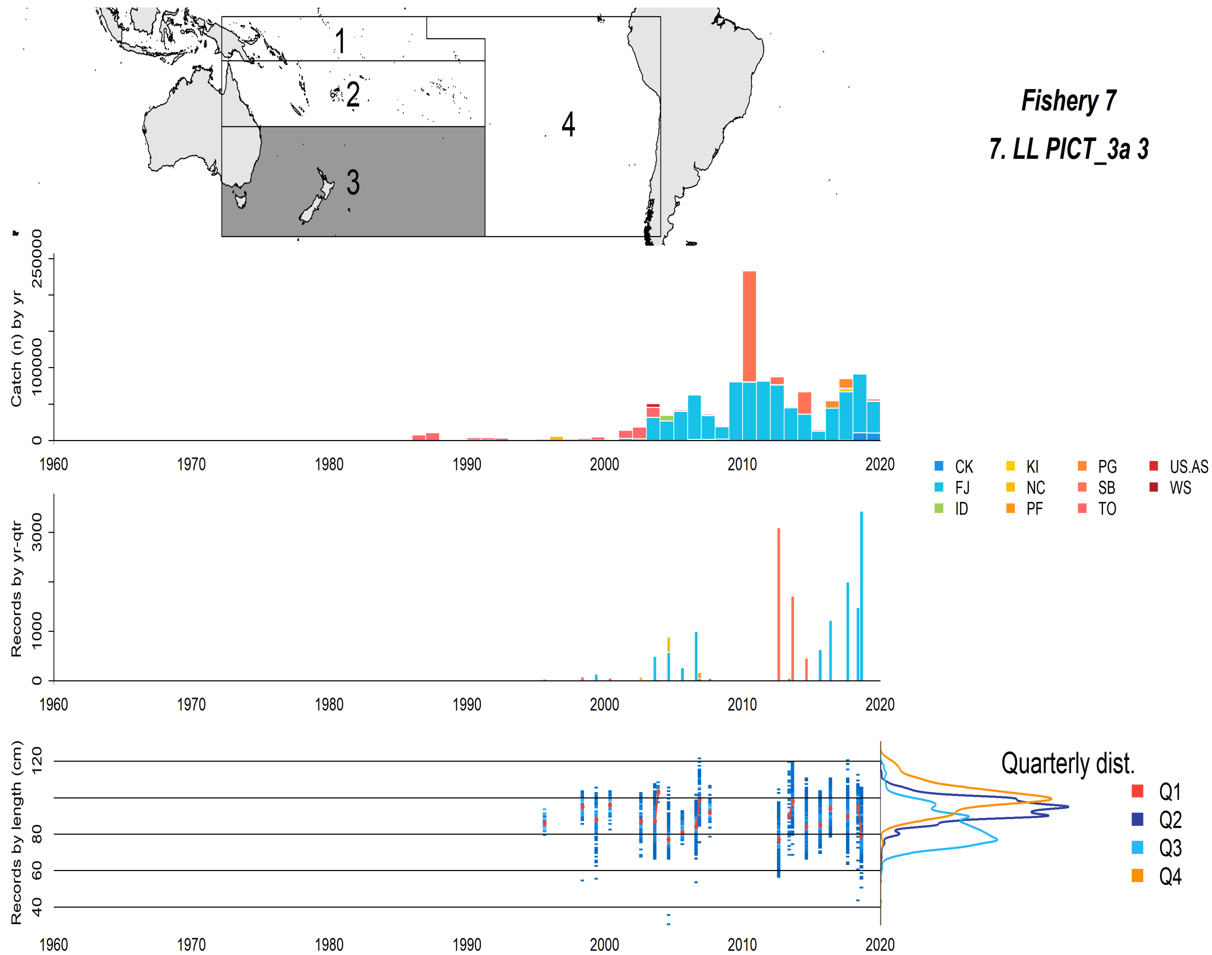

Figure A.7: Summary of raw data available for fishery 7 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

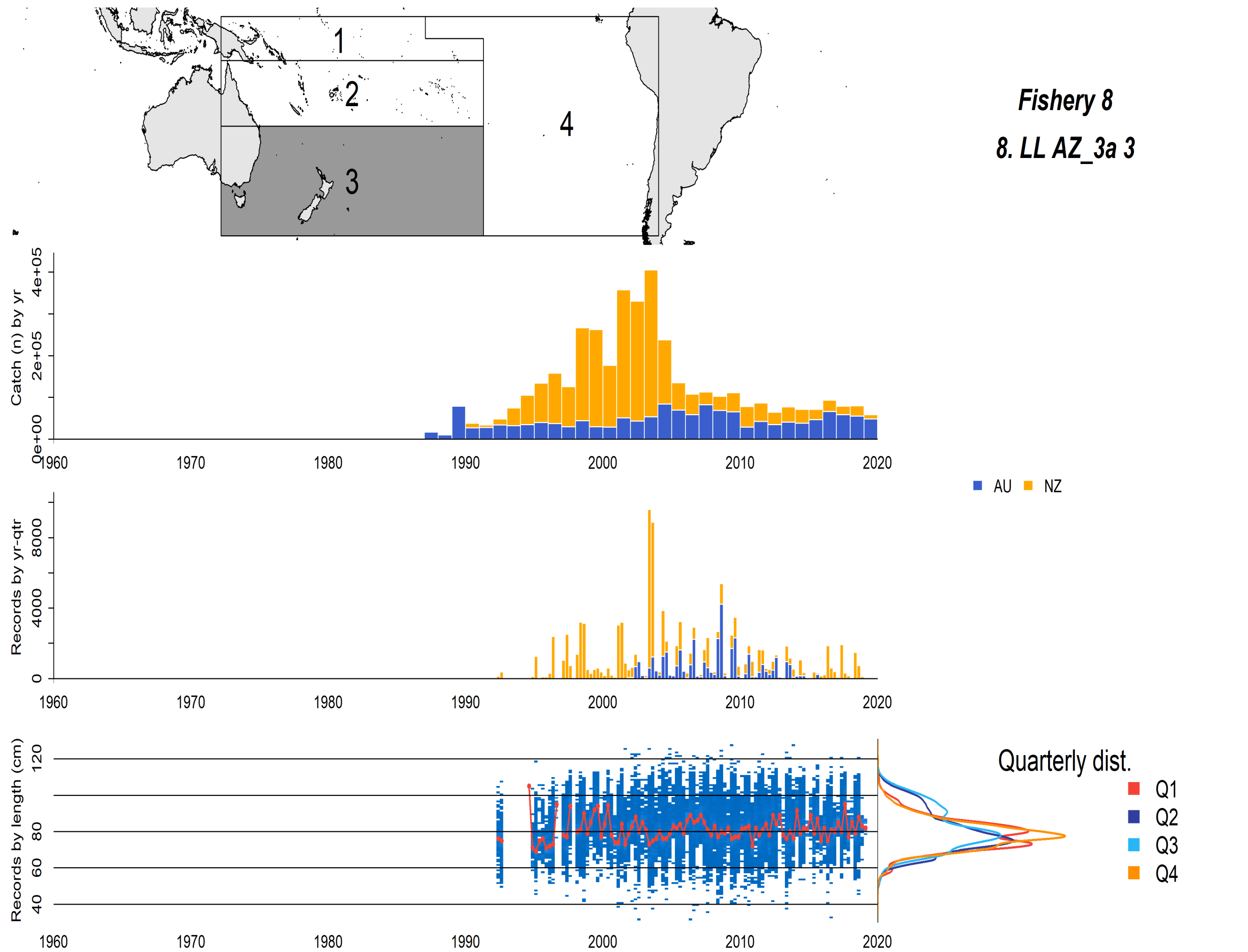

Figure A.8: Summary of raw data available for fishery 8 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

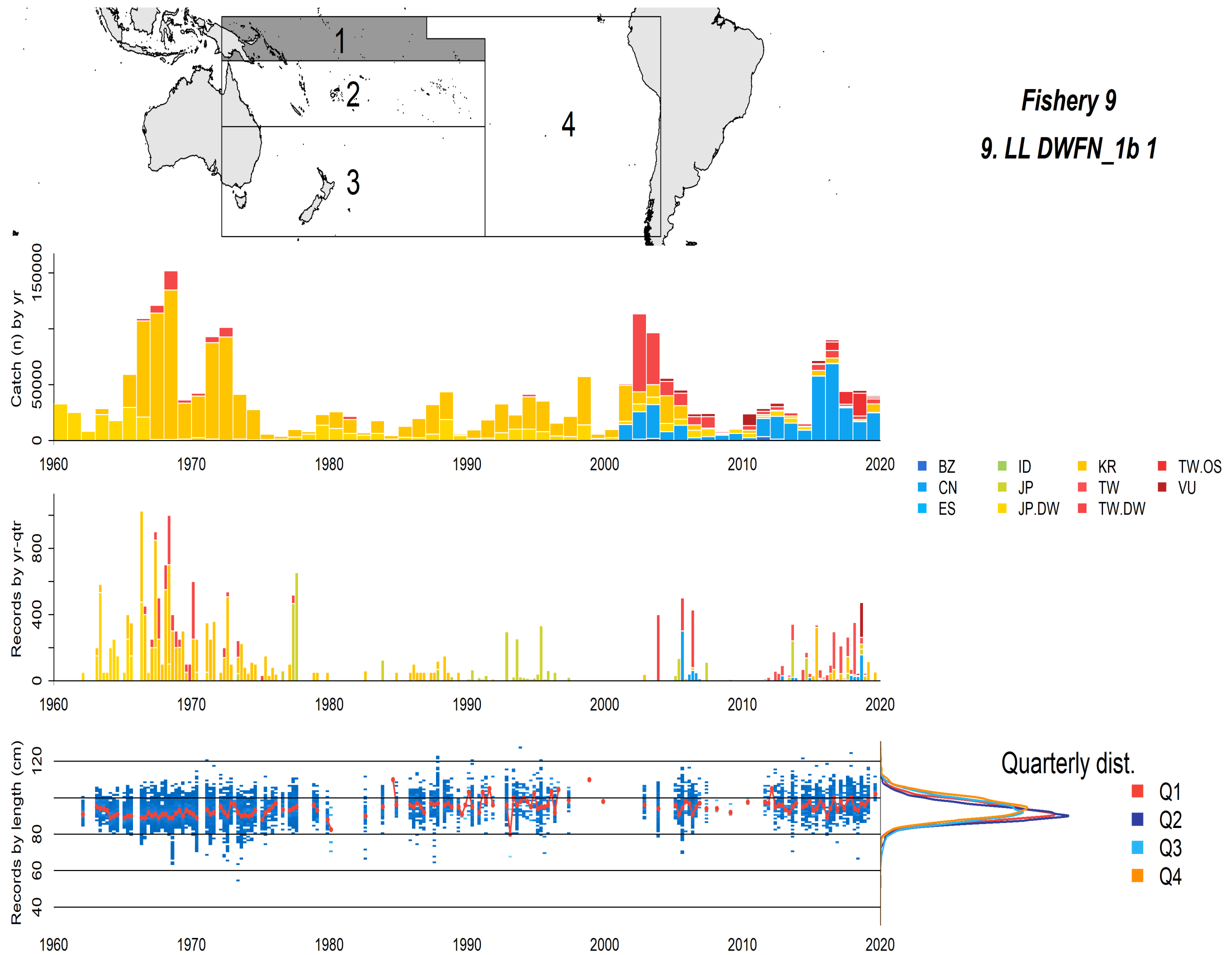

Figure A.9: Summary of raw data available for fishery 9 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

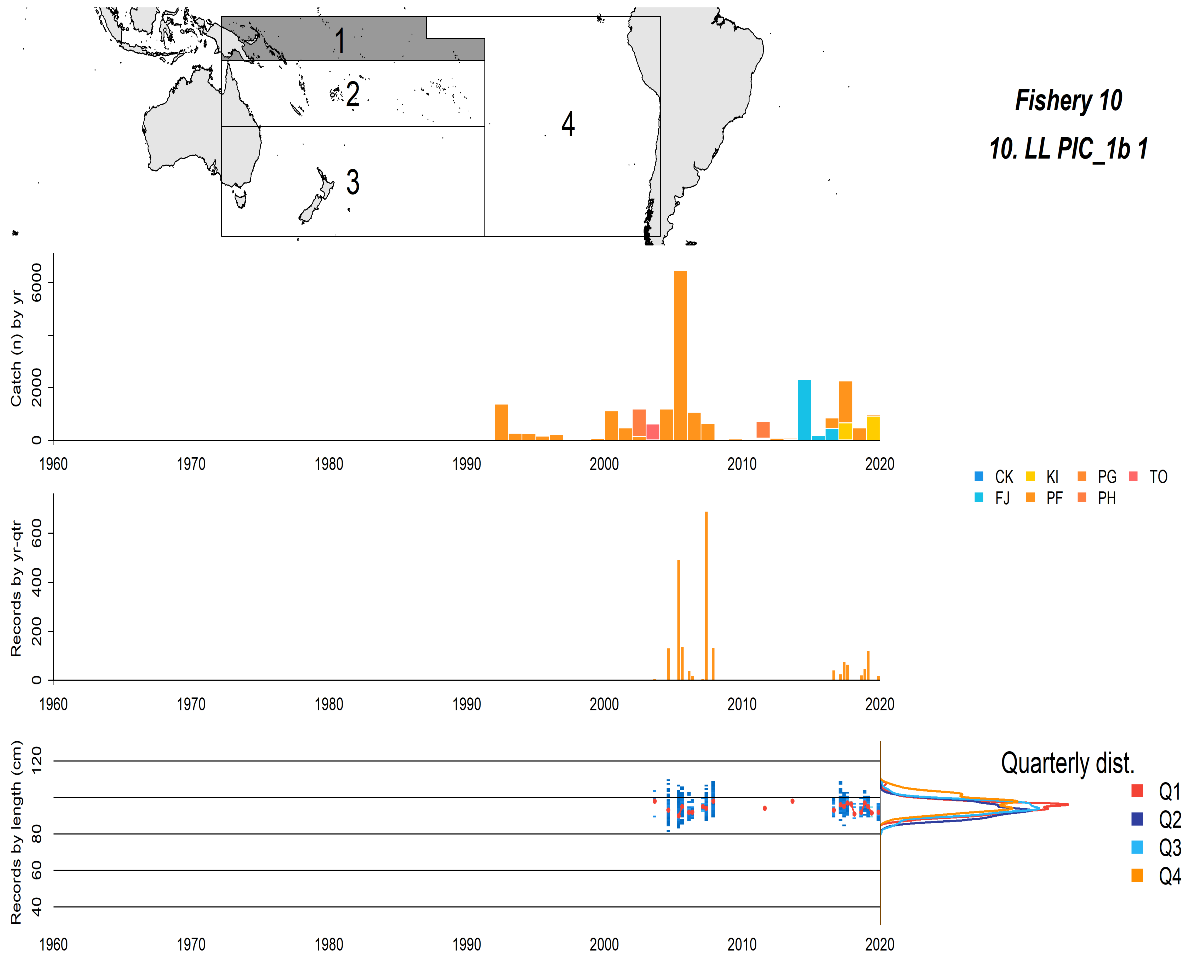

Figure A.10: Summary of raw data available for fishery 10 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

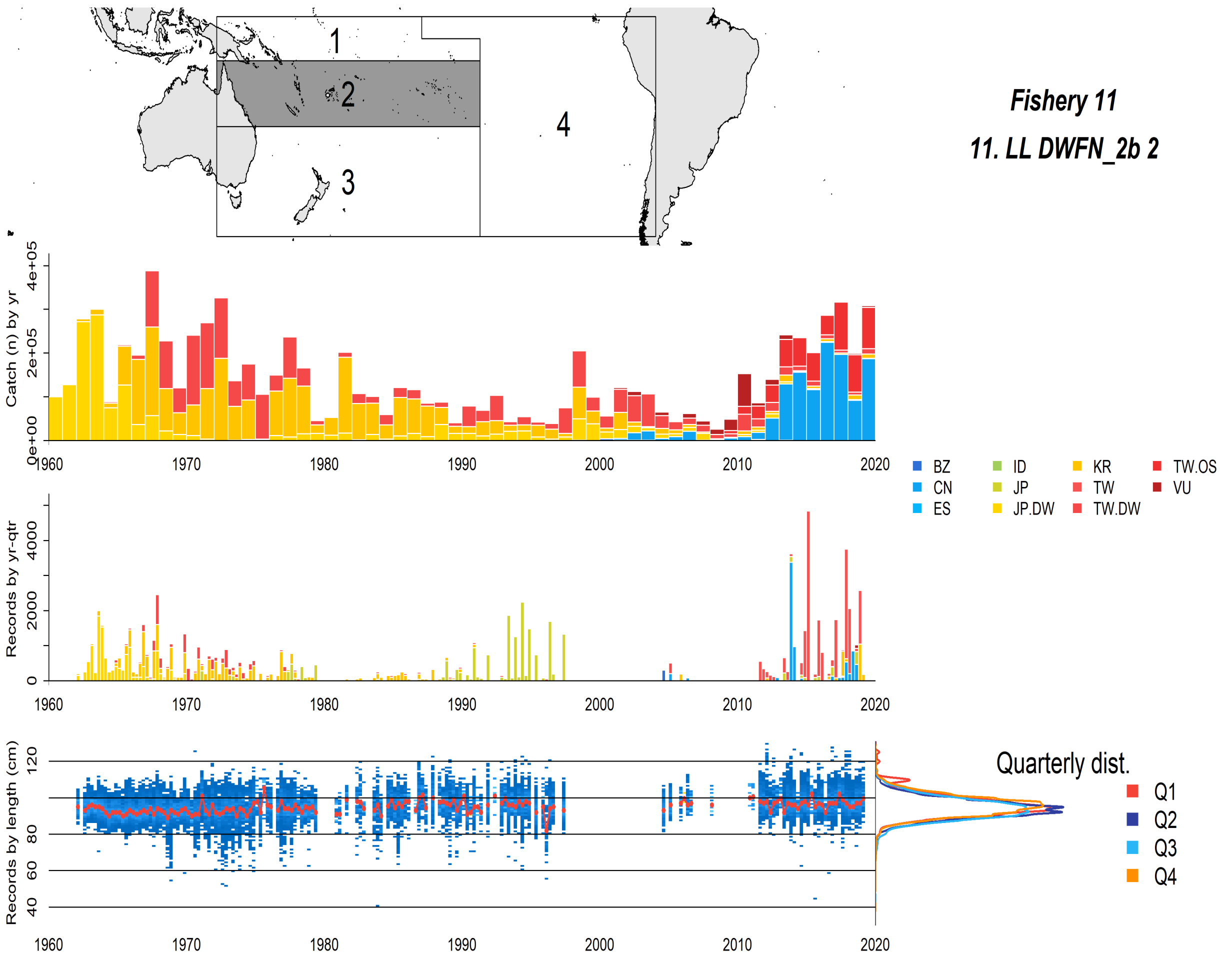

Figure A.11: Summary of raw data available for fishery 11 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

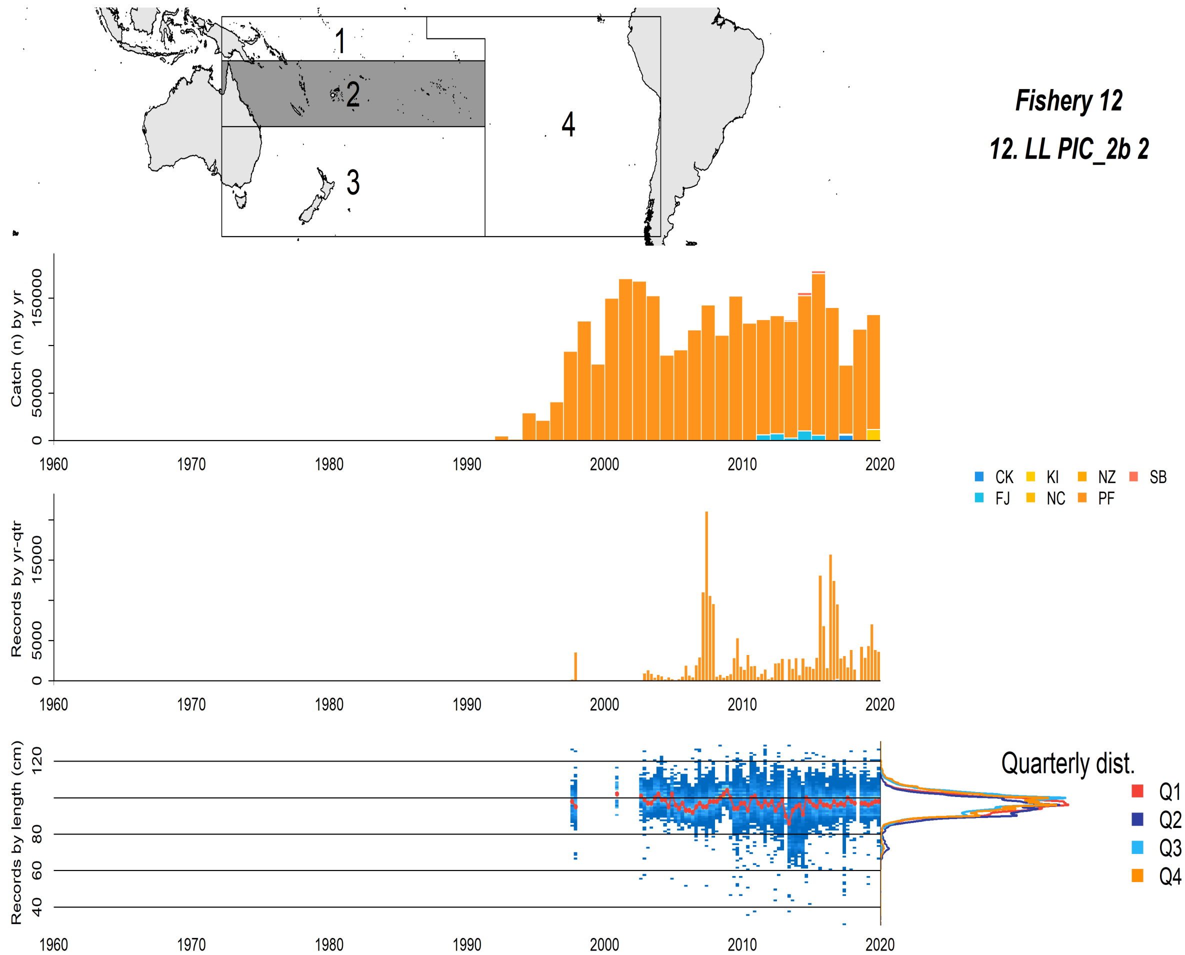

Figure A.12: Summary of raw data available for fishery 12 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

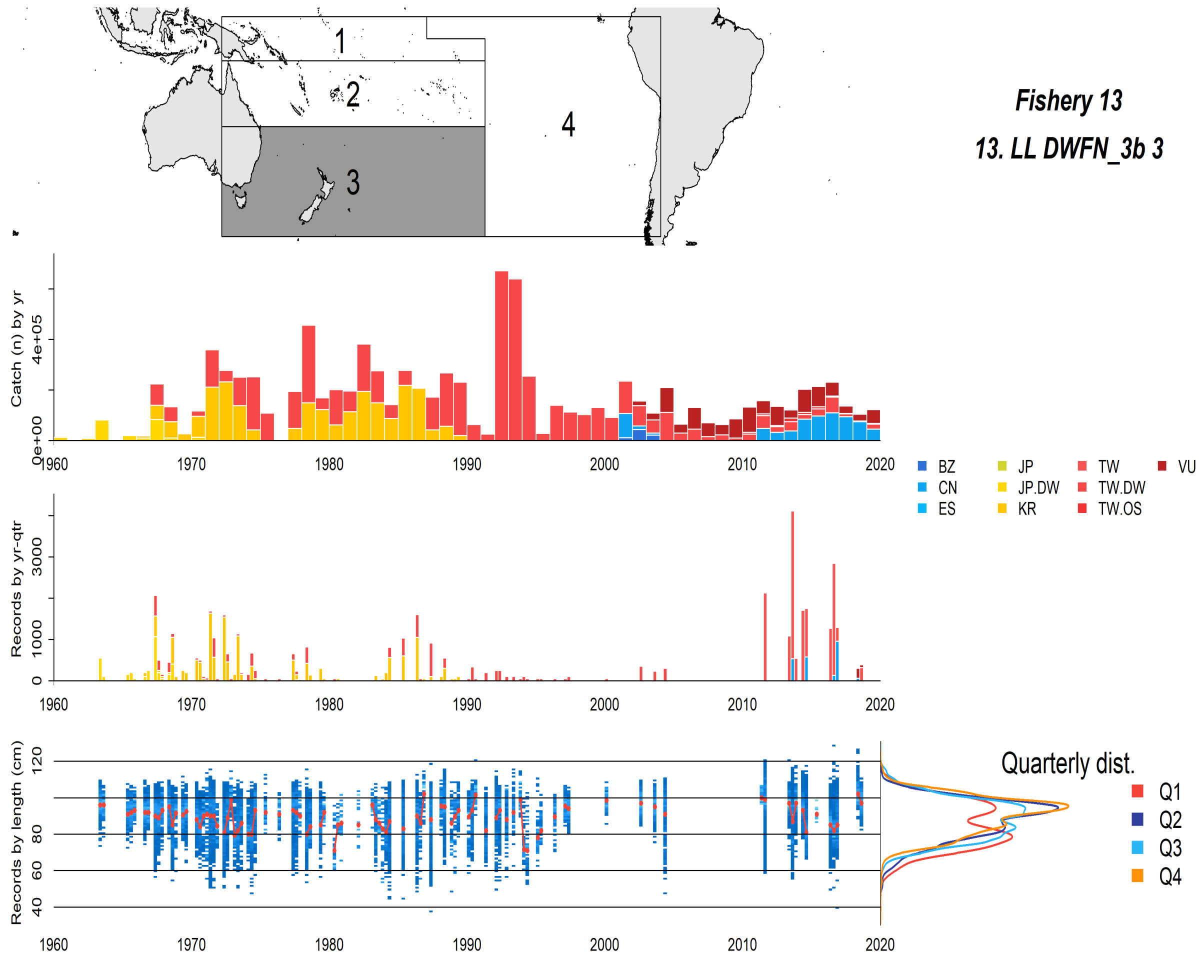

Figure A.13: Summary of raw data available for fishery 13 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

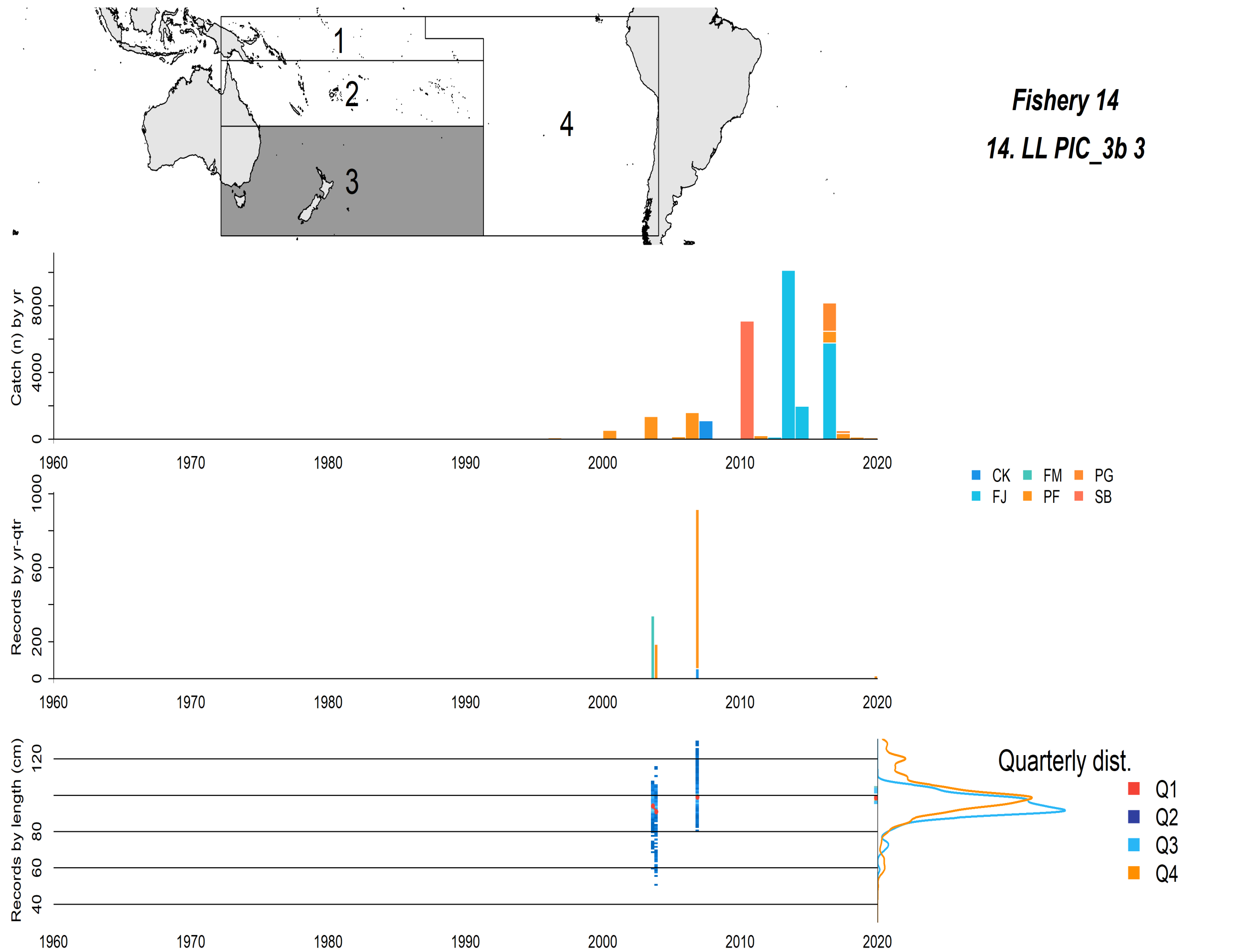

Figure A.14: Summary of raw data available for fishery 14 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

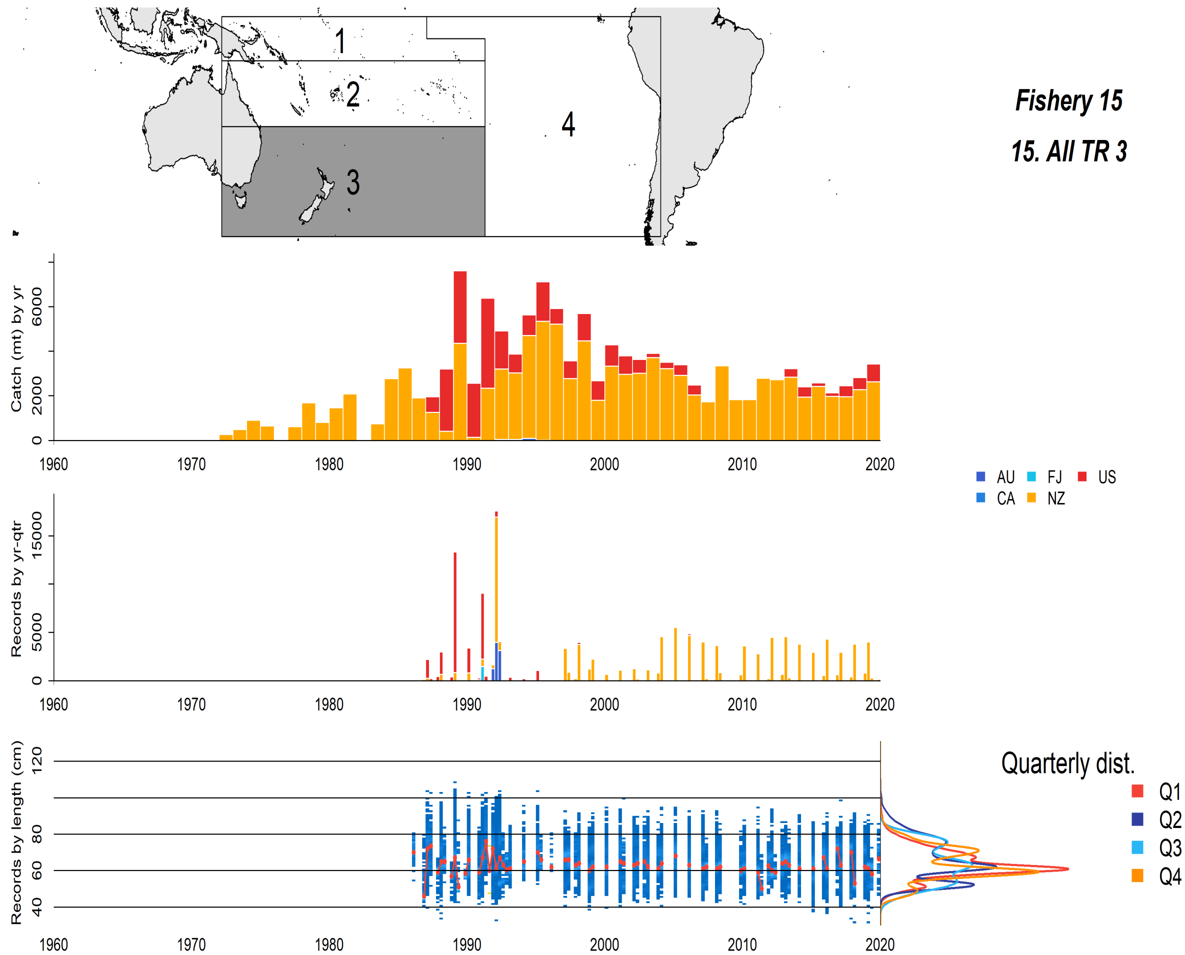

Figure A.15: Summary of raw data available for fishery 15 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

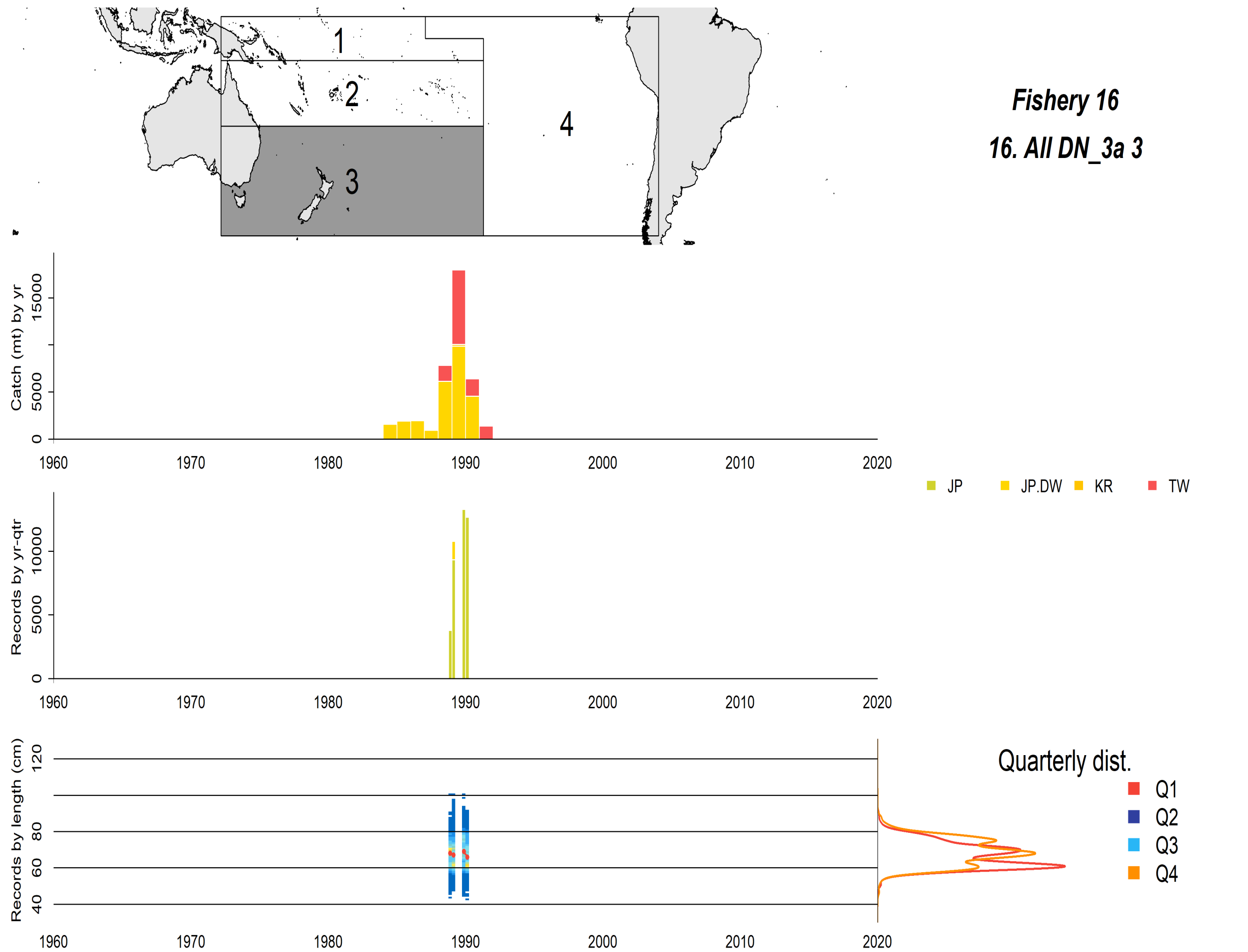

Figure A.16: Summary of raw data available for fishery 16 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

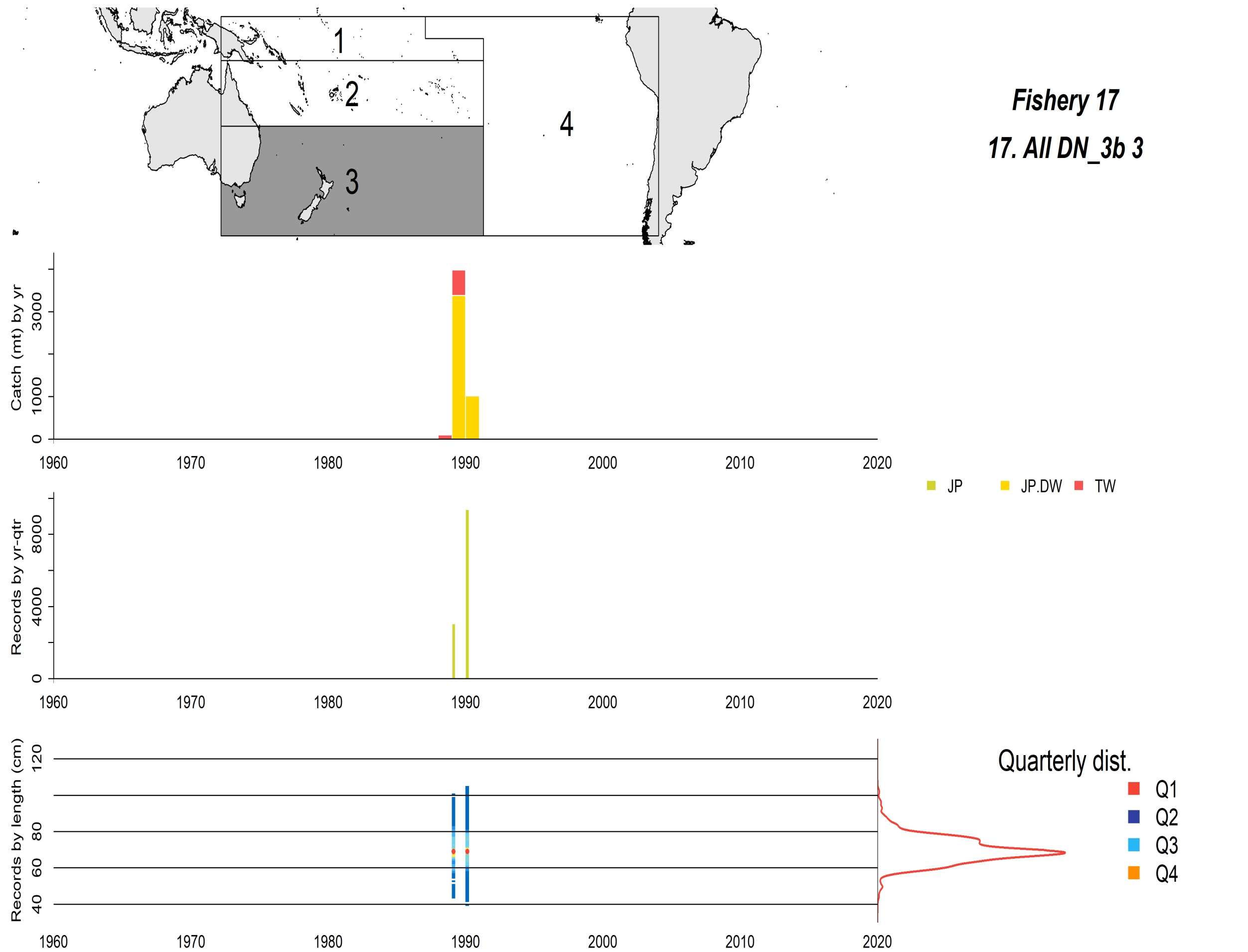

Figure A.17: Summary of raw data available for fishery 17 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

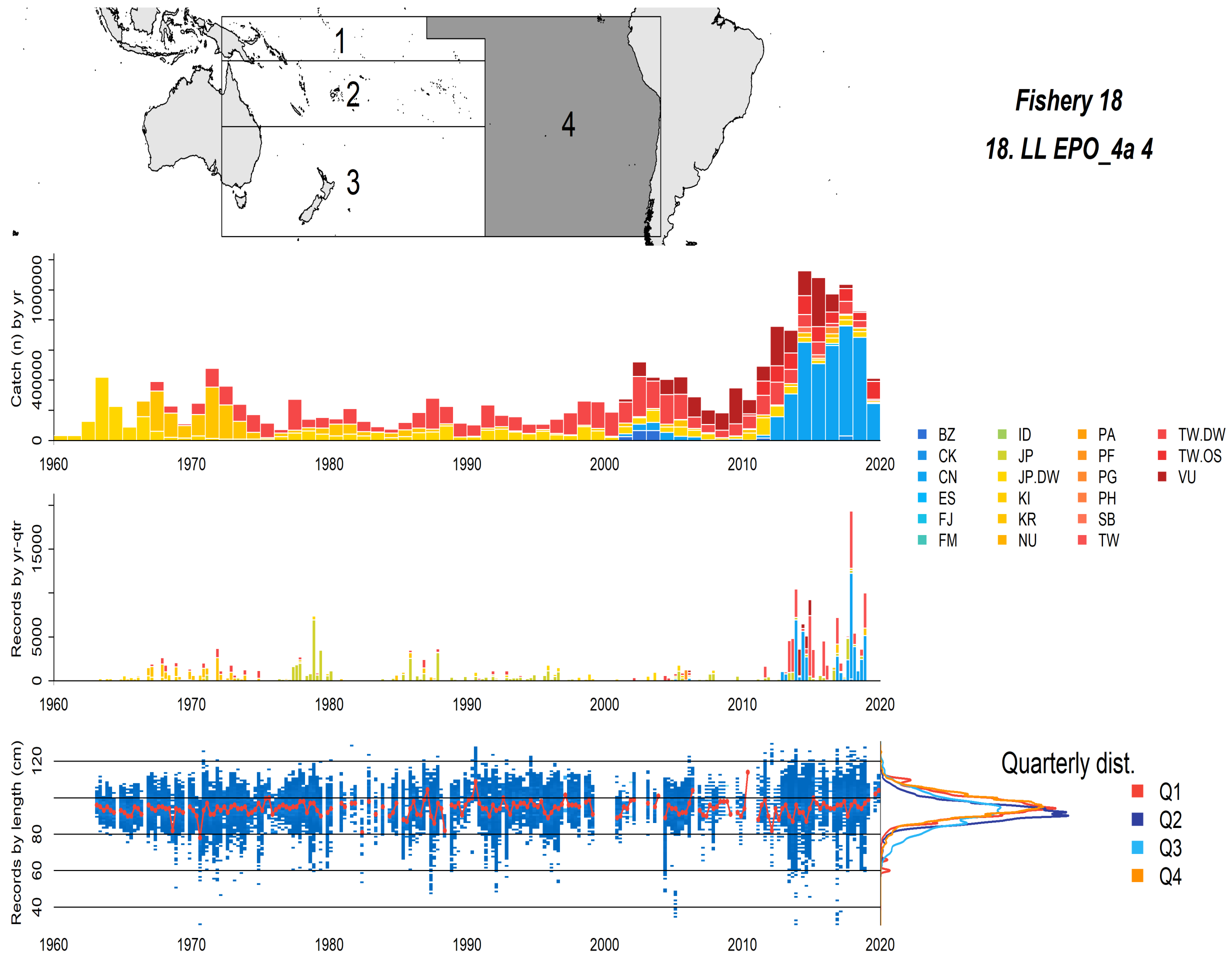

Figure A.18: Summary of raw data available for fishery 18 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

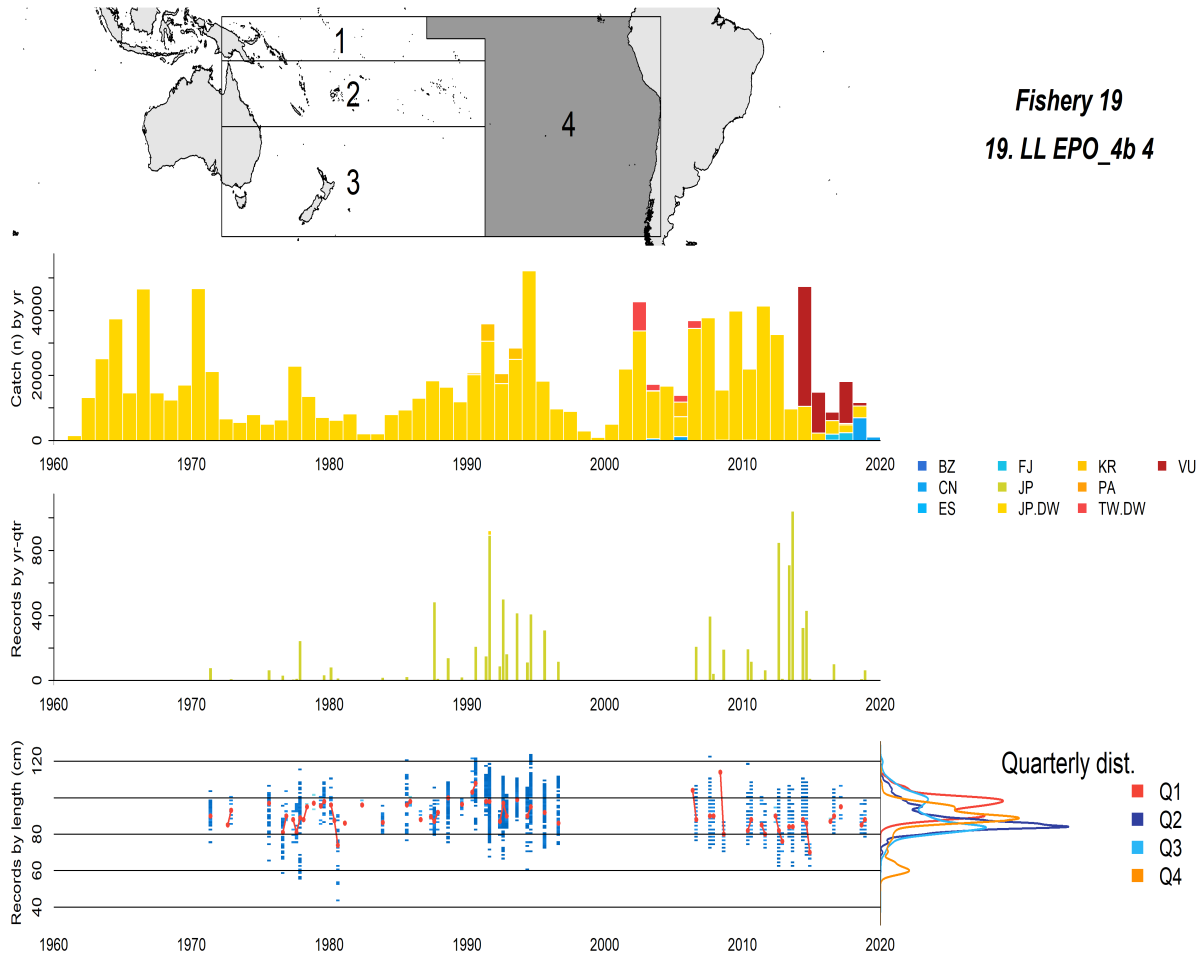

Figure A.19: Summary of raw data available for fishery 19 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

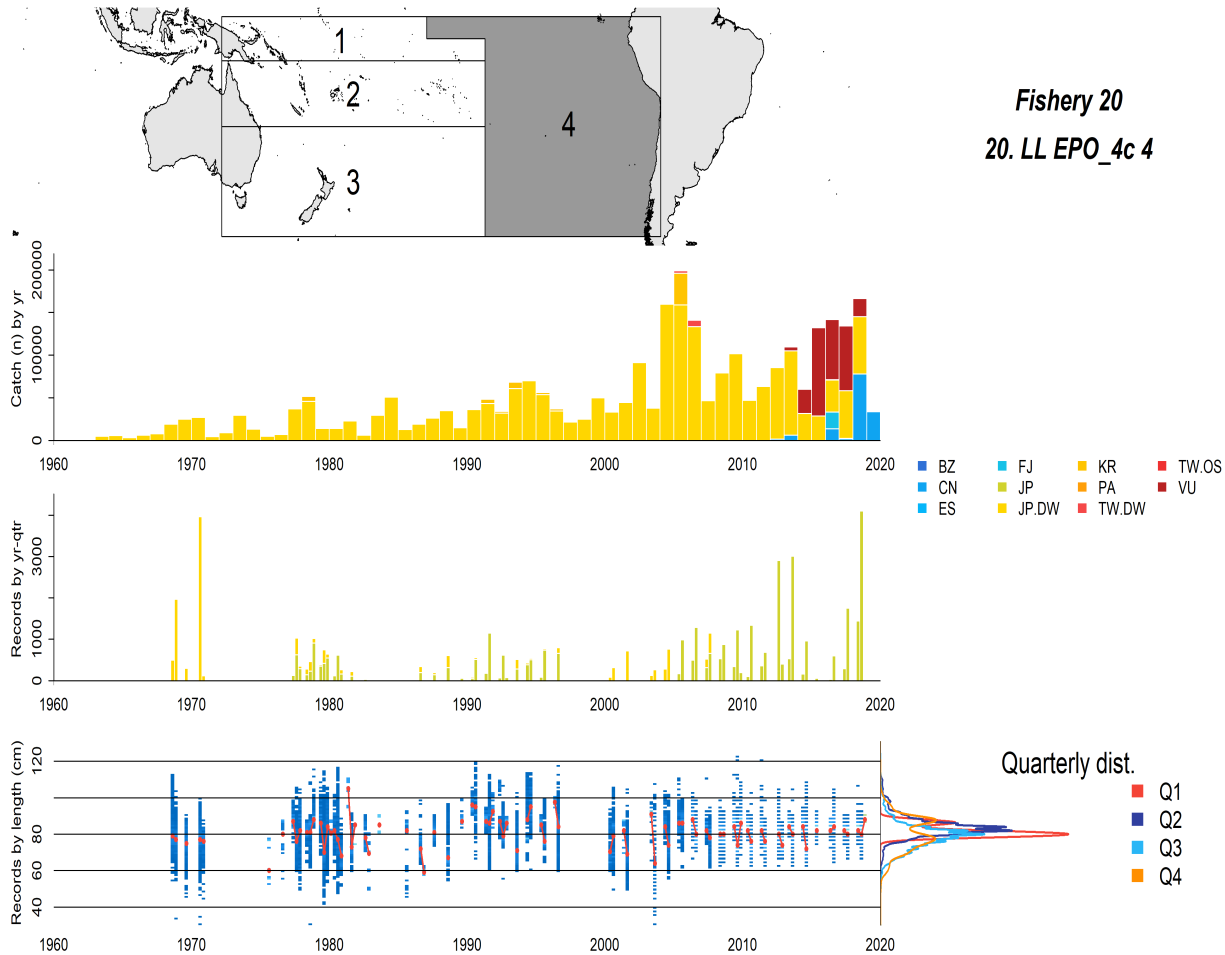

Figure A.20: Summary of raw data available for fishery 20 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

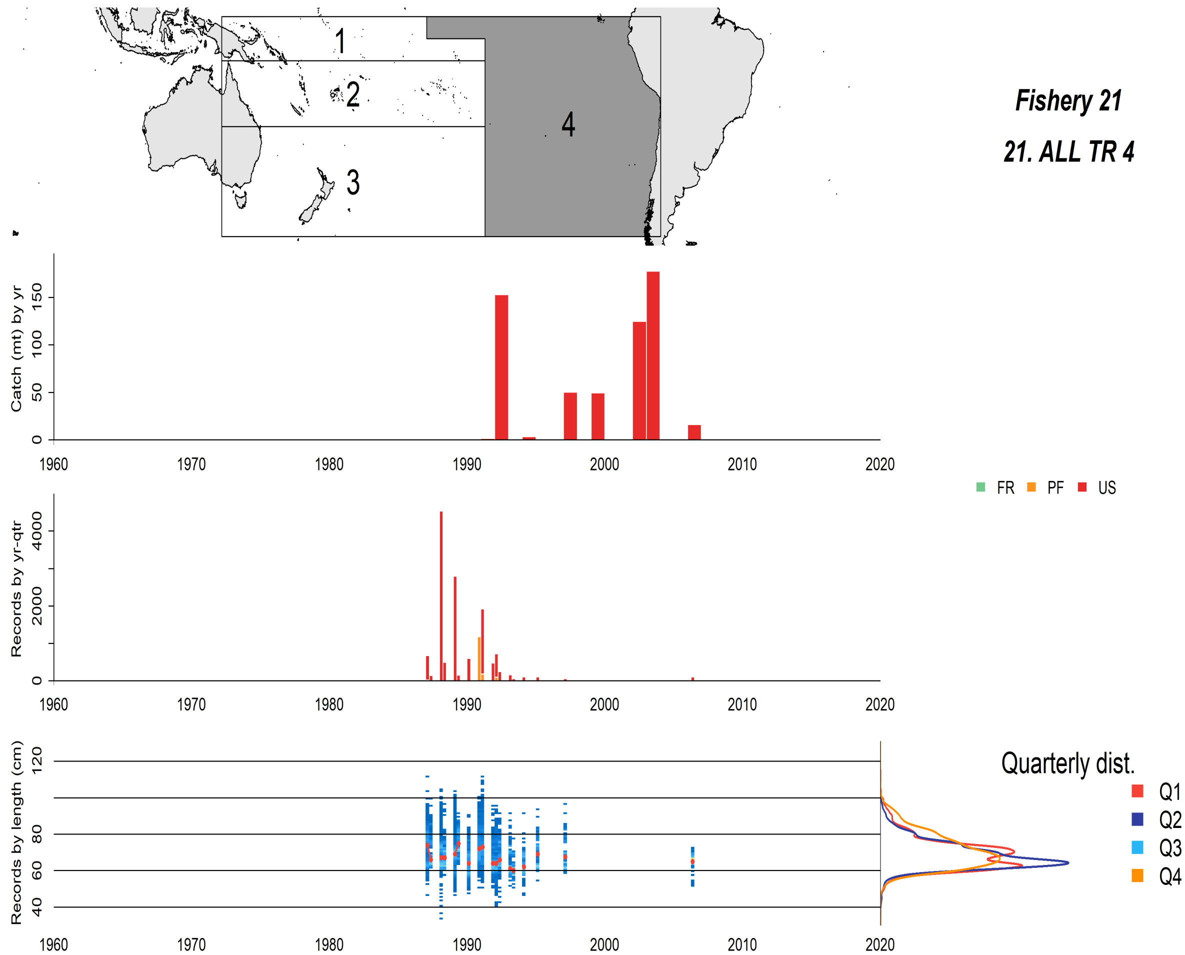

Figure A.21: Summary of raw data available for fishery 21 of the 2021 albacore stock assessment. The panels display: the region of occurrence (top left), the annual catch by fleet within the fishery, in individuals (top middle panel), the annual number of fish with measured length (bottom middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

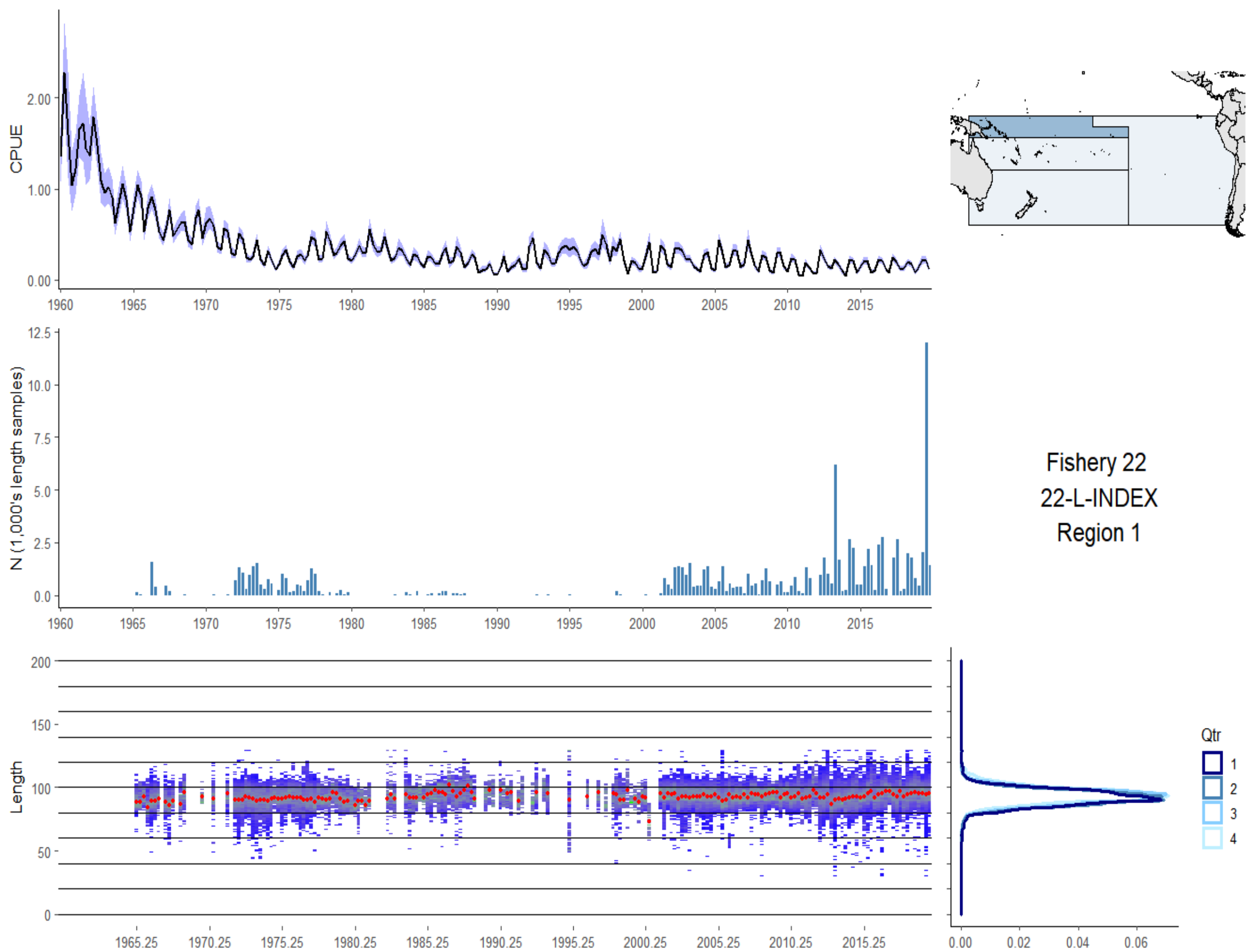

Figure A.22: Summary of data used in the 2021 albacore stock assessment for fishery 22 (an index fishery). The panels display: the standardized CPUE index (top left), the annual number of fish with measured length (middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

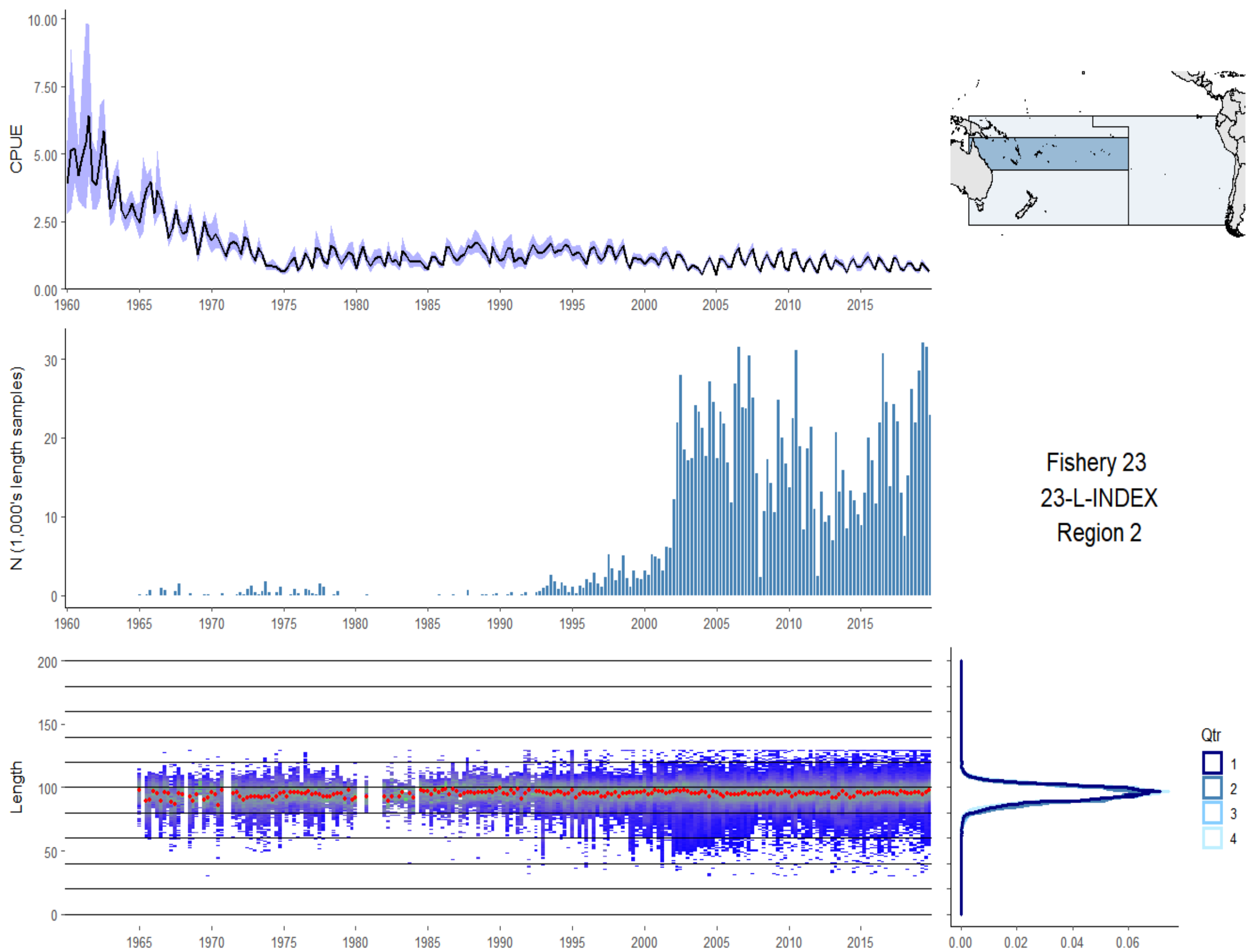

Figure A.23: Summary of data used in the 2021 albacore stock assessment for fishery 23 (an index fishery). The panels display: the standardized CPUE index (top left), the annual number of fish with measured length (middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

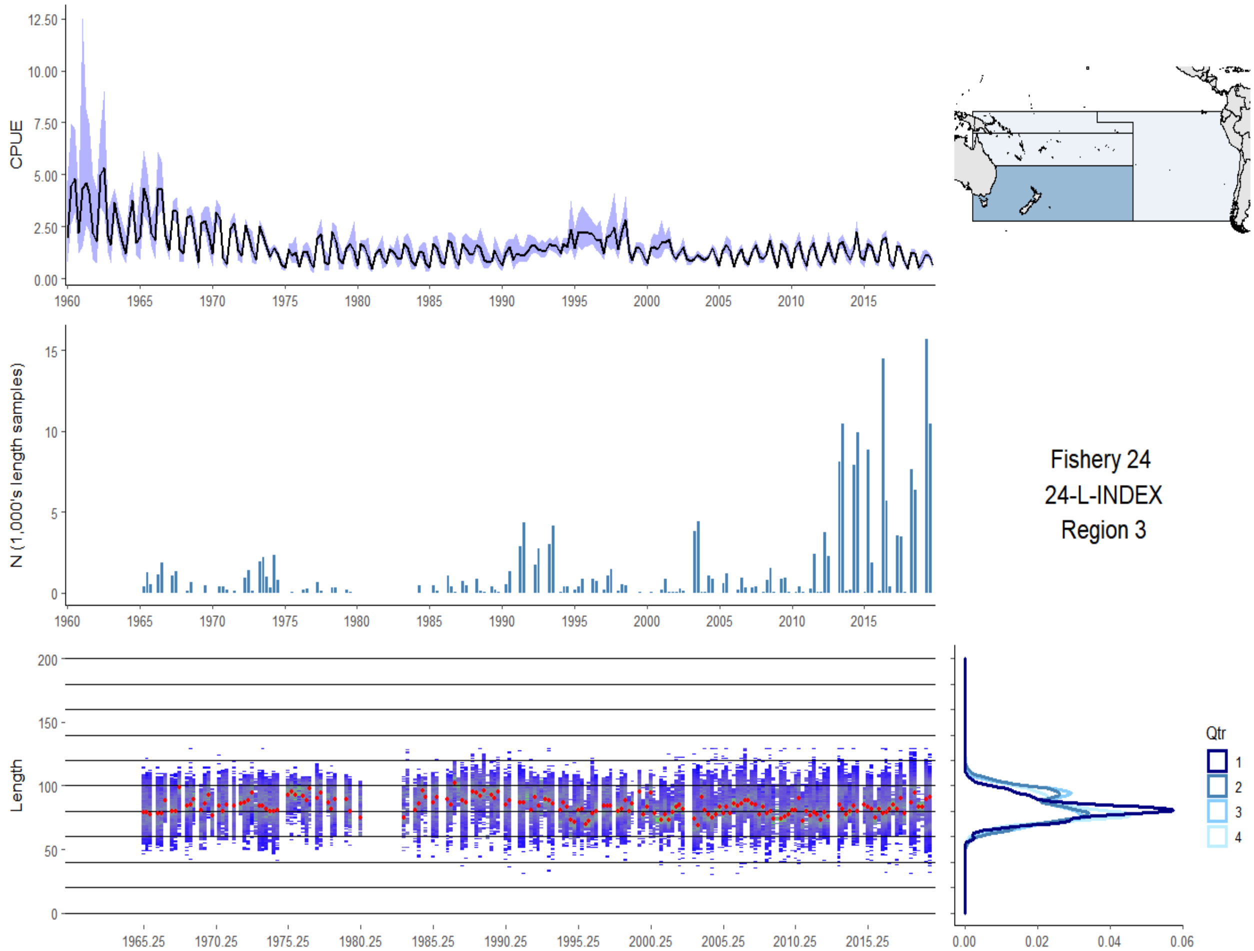

Figure A.24: Summary of data used in the 2021 albacore stock assessment for fishery 24 (an index fishery). The panels display: the standardized CPUE index (top left), the annual number of fish with measured length (middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

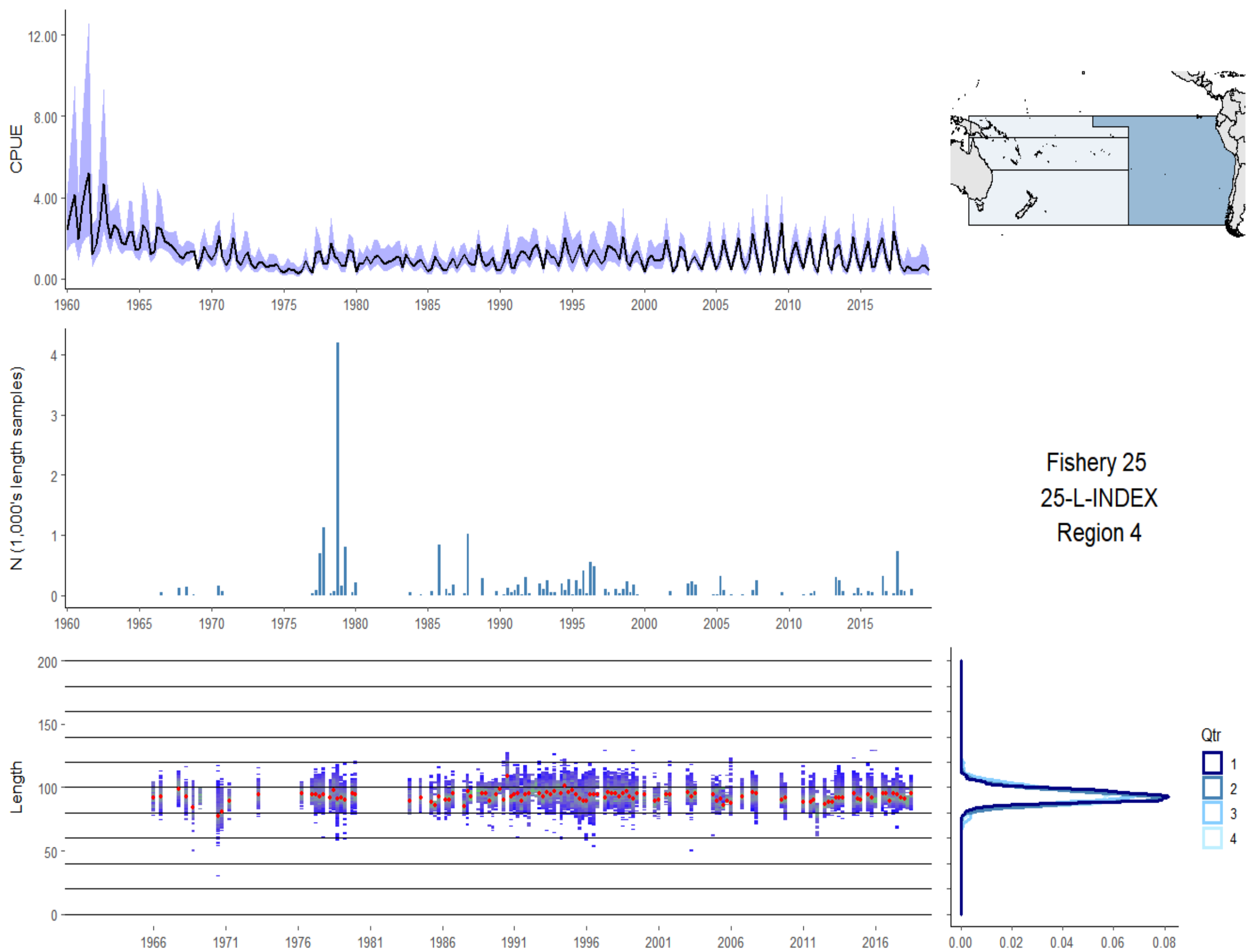

Figure A.25: Summary of data used in the 2021 albacore stock assessment for fishery 25 (an index fishery). The panels display: the standardized CPUE index (top left), the annual number of fish with measured length (middle panel), trends in length composition data with the median highlighted in red (bottom), and the overall size distribution over the time-span of the fishery (bottom right).

B Split CPUE time series comparison

As mentioned briefly in the document, we did some preliminary analyses to evaluate the implications of splitting the CPUE time series. The motivation was two-fold: i) to address the discussions around the importance of the change to the mainline material around the mid-1990s, and ii) the availability of additional data elements from the more contemporary time period (e.g. vessel id and oceanographic covariates) with which to account for catchability (and/or density) changes. There were some differences between the models, but overall, the general trends were quite similar. Perhaps a bit surprisingly, the more complex model for the recent time period didn't have much effect on the resulting indices. As a result, we opted to continue with a single CPUE time series, but additional consideration may be warranted with respect to the use of and implications associated with splitting CPUE time series.

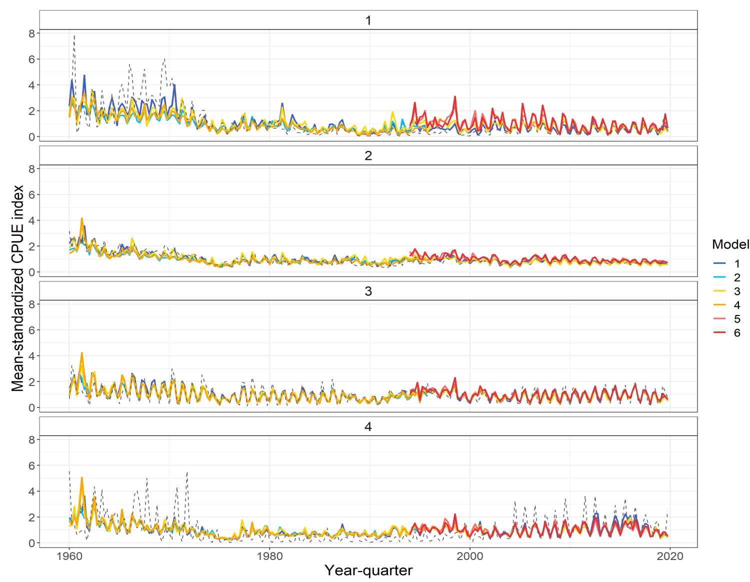

Figure B.1: Split time series model comparison, as presented at the PAW in March 2021.

C PIT residuals

Briefly, the *DHARMa* package (Hartig and Lohse, 2017) uses a simulation-based framework to produce readily interpretable and scalable residuals for generalized linear mixed models, and has been adapted as the default approach for *VAST* models. The model output is used to simulate n new data sets, under the assumption that if the model is correctly specified and the parameters known, the residuals are an iid (independent and identically distributed) sample from the standard uniform distribution. The simulated data are then compared to the observed, to see where the observations lie within a larger set of predictions, based on the estimated model parameters and structure. Ideally, the observed value would fall in the center of the simulated values, yielding a residual value 0.5. A residual value of 0 means that all the simulated values are greater than the observed value, and similarly, a value of 1 suggests all simulated values are below your observed value.

Probability-integrated-transform (PIT) residuals are generated as the 'DHARMa' residuals, the difference being that they are appropriate for discrete error distributions (e.g. binomial, Poisson), that would not produce identically distributed residuals. A standard approach for discrete distributions is to jitter the responses and simulated values by +/-0.5, when duplicates are detected. J. Thorson and others raised the issue that for delta-models, there is a mass at 0 and then some continuous distribution of positive catch rates (see GitHub discussion for additional detail https://github.com/florianhartig/DHARMa/issues/168). In these cases the standard jitter of 0.5 could influence the scale of the residuals, and potentially suggest overly optimistic diagnostics for a model fit. Given that many CPUE standardization models are delta-models (with a binomial component), PIT residuals offer an appropriate diagnostic solution.

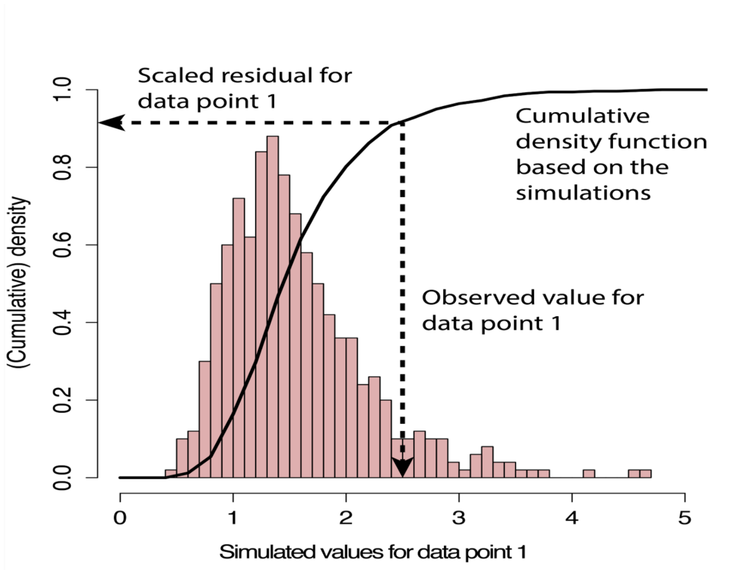

Figure C.1: Illustration of the DHARMa residual concept from the *DHARMa* R package vignette (Hartig and Lohse, 2017) (https://cran.r-project.org/web/packages/DHARMa/vignettes/DHARMa.html).

D Supplemental figures from the CPUE standardization analyses

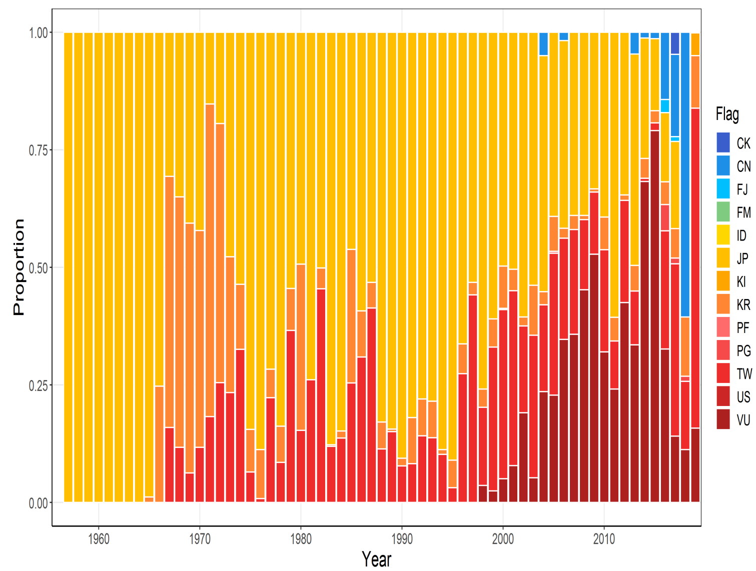

Figure D.1: Proportion of the EPO albacore catch (in numbers) associated with each flag and time period.

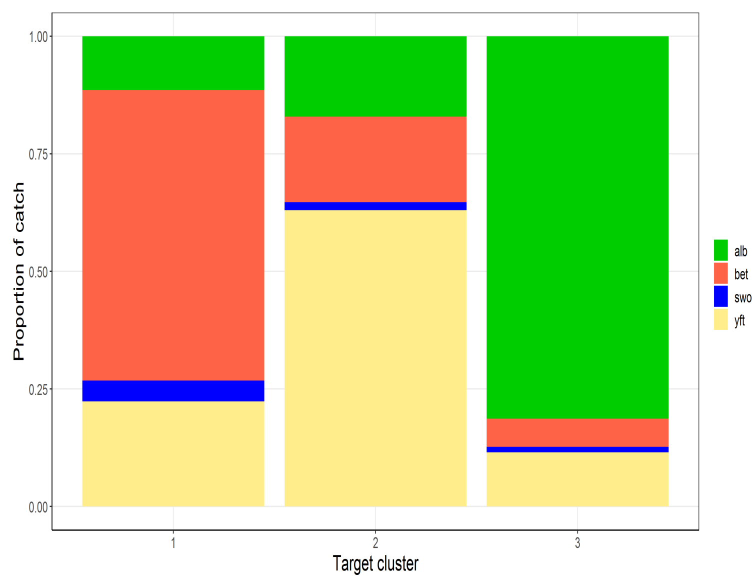

Figure D.2: Aggregate species composition associated with each of the three targeting clusters used in the analysis.

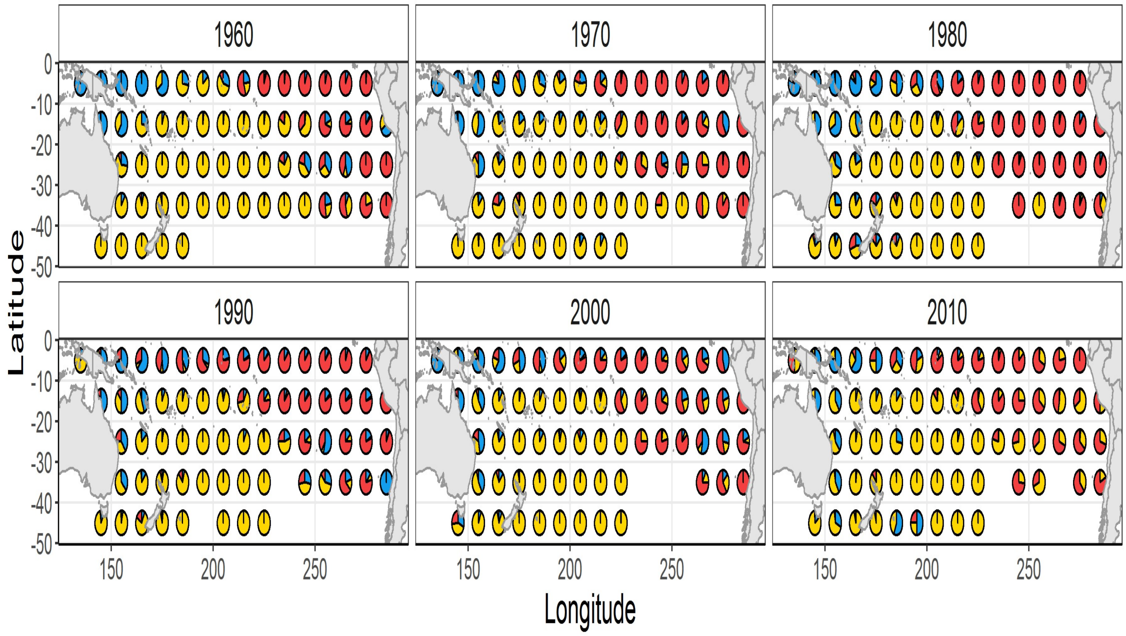

Figure D.3: Spatial distribution of sets associated with each of the three targeting clusters, aggregated across by decade. The targeting cluster is representative of broad targeting practices, and does not necessarily map directly to an individual species.

E Model spatial and fishery structure background

SPC Pre-assessment workshop preliminary information document 1

2021 South Pacific wide albacore assessment: spatial structure and fishery definitions

Purpose: The purpose of this information document is to outline a proposed approach to the model spatial structure and fishery definitions for the 2021 south Pacific albacore assessments. This will hopefully reduce the discussion time required during the workshop on this key aspect of the assessment plan, allowing more time for other topics.

Key contributors to the discussions on the spatial structure and fishery definitions have included:

Claudio Castillo Jordan (SPC), Matthew Vincent (recently SPC), John Hampton (SPC), Paul Hamer (SPC), Graham Pilling (SPC), Sam McKechnie (SPC), Tiffany Vidal Cunningham (SPC), Nicholas Ducharme-Barth (SPC), Haikun Xu (IATTC), Cleridy Lennert-Cody (IATTC).

(references are hyperlinked, hover over and press ctrl key)

Background

As directed under the WCPFC stock assessment schedule, the 2021 south Pacific albacore assessment will span the entire south Pacific encompassing the southern hemisphere area of the western and central Pacific Ocean (WCPO) and eastern Pacific Ocean (EPO) regions under the management jurisdictions of the WCPFC and the IATTC respectively. The previous two assessments were in 2018 (Tremblay-Boyer et al. 2018) and 2015 (Harley et al. 2015) and considered the WCPFC convention area (including the overlap region) only (Fig. 1). There is no previous standalone assessment of albacore in the southern EPO region, however, the 2012 south Pacific albacore assessment conducted by SPC, did include the EPO as a fishery strata (Hoyle et al. 2012). The 2021 assessment will be the first attempt at a spatially structured assessment of albacore across the entire south Pacific Ocean. The first key structural issue we are faced with in developing this new assessment is the spatial structure and fishery definitions to apply. This document provides an overview and justification for the approach we are proposing that has been developed by SPC and IATTC assessment scientists collaborating on the assessment.

To develop a proposed spatial structure and fishery definitions for this assessment we considered a range of information:

- The previous assessment structure (Tremblay-Boyer et al. 2018)
- Available tagging data
- Other information related to movement and population structures (i.e., models presented in review papers, Nikolic et al. (2017), expert opinions, modelling of spatial dynamics (SEAPODYM) (Senina et al. 2020))
- Length composition data
- Fishery coverage by fleets/gears
- Management jurisdictional boundaries

The starting point for the new assessment is always the previous assessment, acknowledging that considerable thought and discussion went into revising the spatial structure of the 2018 assessment area (i.e., WCPFC convention area) compared to the 2015 version (Harley et al. 2015) . We also initially considered that it would be desirable to retain the separation of the IATTC and WCPFC management regions in the 2021 assessment so that management advice can be provide at the Regional Fishery Management Organisation (RFMO) level. The treatment of the overlap region (Fig. 1), where management regimes under WCPFC and IATTC could both influence fishing is discussed further below.

The spatial structures from the last three assessments are shown in Figure 1. The 2012 assessment was the last that considered the entire south Pacific. This assessment was a single region model with the fisheries stratified into six areas (i.e., area-as-fleets) (Fig. 1). The 2015 assessment introduced a fully spatially structured model with 8 regions, however, there were issue with complexity of this structure and positioning of model region boundaries in relation to tagging data. The spatial structure was therefore simplified from the 2015 to 2018 assessment after advice from the 2018 PAW for the main reason that there was a *'relative lack of information to inform MULTIFAN-CL on movement between regions, in part due to many of the tag releases occurring on or near the border of the old region structure'*. This refers to the boundary between regions 1-4, 2-5, 3-6 in the 2015 structure (Figs. 1, 2).

We propose to continue with the spatially structured approach for the 2021 assessment but further simplify the WCPO regions by the removal of the boundary between regions 2-4 and 3-5 applied in the 2018 model structure (150°E) (Fig. 1). This seems appropriate considering most of the second group of tag releases sits right on this boundary (Fig. 2a). This boundary was used in previous assessments primarily to separate the overlap region into separate model regions. From a modelling perspective having separate model regions for the overlap area seems inappropriate given the limited data to support this.

The tagging data for the WCPO perhaps provides more information on latitudinal (south to north) than longitudinal movement (at least between the two southern regions of the WCPO). Further, most tagged albacore for the WCPO involve releases of mostly juvenile <80 cm (about the length at 50% maturity) (Fig. 3). The pattern of displacement northward from the southern tag release locations has been used as supporting evidence that south Pacific albacore tend to move and reside further north as they grow, with the southern regions being typically comprised of smaller fish (Fig. 4). The observations of a south-north movement trend for south Pacific albacore as they grow, and an annual summer spawning migration to waters closer to the equator (0-20°S and surface temps >24°C), i.e., Farley et al. (2013), have led to the development of conceptual models of life-history movement dynamics supported by quantitative modelling of the spatial dynamics of south Pacific albacore (SEAPODYM, Senina et al. 2020) (Fig. 7).

The life-history movement models in the WCPO, particularly the occurrence of smaller fish in the more southerly cooler regions also seem to occur in the EPO. Length composition data for the EPO shows a similar pattern where small fish predominate in the colder Humboldt Current region off Chile and Peru (Fig. 6). However, there is poor knowledge of spawning areas in the EPO. Assuming similar temperature for spawning in the EPO as the WCPO, it is possible that spawning could occur in the north western region of the EPO. This is reflected in the SEAPODYM estimate of average larval distribution, which is estimated to extend eastwards to around 110W (Fig. 7). For this assessment we assume that recruitment into the EPO could be derived from spawning sources in both the WCPO and EPO but acknowledge this is an area requiring more information. There are no tag-recapture data for albacore released in the EPO region to inform movement and a regional model structure for the EPO would appear to be problematic. However, there are several observations of fish tagged in the southern WCPO being recaptured further east in the northern and southern region of the EPO, supporting the suggestion that fishery recruitment in the EPO is at least partly derived from reproduction in the WCPO (Fig. 2b).

Overall, the information from tagging and length composition data show smaller fish being more prevalent in catches from cooler waters, i.e. <24°C, and moving to warmer waters as they grow. This life-history movement pattern underpinned the latitudinal boundary between regions 2 and 3 for the WCPO in the previous two assessments, placed at 25°S (Fig. 1). For the 2021 assessment we see no reason to change this boundary based on any 'new' information and so propose to retain it.

The boundary between regions 1 and 2 in the WCPO was set at 10°S for the previous two assessments. This corresponds to the southern boundary of the WCPO tropical longline fishery (20°N – 10°S) and seems logical from a fishery structure/targeting and data perspective, but also a management advice perspective. As this boundary was also supported at previous Pre-assessment Workshops (PAWs) and there have been no changes to the tropical longline fishery region of operation, we propose to retain this model region boundary for the WCPO in the 2021 assessment.

Given the lack of data on movements (no tagging) to inform a spatially structured approach we propose that a single spatial region is applied to encompass the entire EPO. However, acknowledging that there is spatial and seasonal fishery structure in the EPO an areas-as-fleets approach is proposed to develop the fishery definitions for the EPO. The methods similar to those described by Lennert-Cody et al. (2010) were used to allocate areas (cells) for fleet groupings in the EPO. Briefly, a regression tree-type approach was used to explore spatial and seasonal structure in length-frequency distributions. Predictors were quarter; cyclic quarter; 5° latitude; 10° longitude but year was not used as a predictor. The analysis will be described further in the PAW presentation but resulted in a proposed three area structure to define the EPO fisheries (Fig. 9). This structure explained 22.3% of the variability in the length composition and was better suited to the spatial catch and data distribution than more complex structures that only explained a minor amount of additional variation (i.e., 5 area options explained 25% of the variation), but suffered from low numbers of observations and low catch in some areas to inform the model.

Other information on biological stock structure from genetic and otolith chemistry studies, have limitations based on spatial-temporal sample coverage, but do not provide clear evidence for separate genetic stocks across the south Pacific region, but suggest that some meta-population structuring may be present (Macdonald et al. 2013, Nikolic et al. 2017, Anderson et al. 2019, and refs therein). It is currently considered that the stocks north and south of the equator are separate for the purpose of fisheries management with limited movements across the equator but apparently enough exchange to prevent strong genetic differentiation (Nikolic et al. 2017).

Proposed spatial structure

Based on the considerations described above it is proposed to apply a 4 region spatial structure for the 2021 south Pacific albacore assessment with 3 model regions in the WCPO that include the overlap region, and 1 region for the EPO (Fig. 8).

The overlap area

While we are not proposing to create separate model regions for the overlap area, the approach to treating this region requires consideration from a management perspective. Fishing opportunities in this region could come under influence from Conservation and Management Measures implemented by either the WCPFC or IATTC, and there is a considerable area of high seas in this region. As such it would be useful to have the capability to explore, in projection studies, the implications of different management measures influencing this region for both the WCPO and EPO regions. One way to facilitate this is to include separate extraction fisheries for the overlap region. Fishing mortality scenarios and implications could then be explored with separation of the fishing in the overlap area from the broader regions of the WCPO and EPO. We therefore propose to include overlap region fisheries for this assessment. We can test the sensitivity of the model estimation to this, however as the overlap region fisheries will have the same selectivity as their respective fishery groups across the broader region, we expect it should have no impact.

Fishery structures

Similar to the spatial structure, developing the proposed fishery definitions for the 2021 assessment started with reviewing the 2018 assessment for the WCPO. Due to there being no notable changes in the albacore fisheries since the last assessment, we propose to simply modify the 2018 assessment fishery definitions to account for the 3 region structure and include the option of the separate fishery definitions for fishing in the overlap zone (Table 1).

The fisheries for the WCPO are grouped according to the gear types, model regions and fleets, ie., Distant Water Fishing Nations, Australia/New Zealand, Pacific Island Countries and Territories, longline, troll, and drift net, as per the 2018 assessment. These fishery groupings aim to group fisheries with similar operational selectivity characteristics.

For the EPO the fishery definitions are derived from the areas-as-fleets tree analysis, and as there are three cells/areas proposed three main fisheries are defined. There is also a small amount of catch in the EPO by troll fisheries, particularly during the 1990's. However, there is no size composition information for this catch. To account for this troll catch we have included a fourth region wide fishery that will have selectivity consistent with the troll fisheries in the WCPO (Table 1). Finally, there is a small amount of drift net catch reported for the EPO in the late 1980s early 1990s, that is attributed to the driftnet fleets from the WCPO straying into the EPO. This catch will be included in the driftnet fleets for the WCPO.

For the 2021 assessment, including the overlap fisheries, the are 24 extraction fisheries (Table 1). Note that defined fleets (i.e. DWFN, PICTS, AZ) within each particular model region or area would share the same selectivity and catchability. For example, fishery 1 (1-LL-DWFN) in area a of region 1 will share selectivity and catchability with fishery 9 (9-LL-DWFN) in area b of region 1 (Table. 1, Fig. 8).

Note: One CPUE or 'index' fishery is created for each model region, irrespective of areas-as-fleets, so there are 4 index fisheries for the standardised CPUE analyses (Table 1). The extraction fisheries do not 'individually' contribute to the index fisheries per se, it is just their data that is aggregated to the create the overall region index fisheries. CPUE standardisation and index fisheries will be described in the PAW CPUE presentation but is described in the previous albacore assessment by Tremblay-Boyer et al. (2018).

Request to PAW

We would appreciate any constructive feedback/comments on the proposed spatial structure and fishery definitions for the 2021 south Pacific albacore assessment.

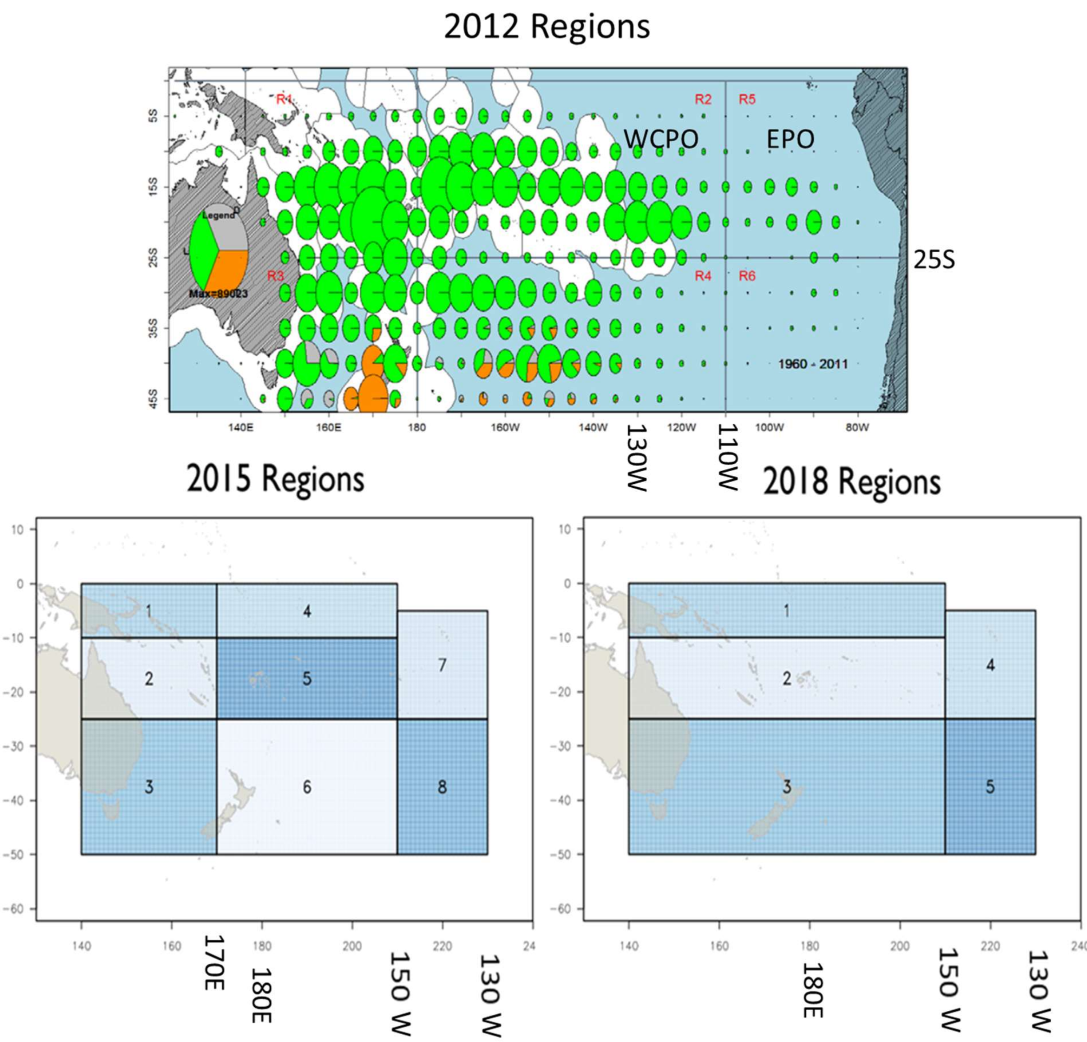

Figure 1. Maps of model regions for the 2012, 2015 and 2018 assessments of south Pacific albacore in the WCPO including overlap region.

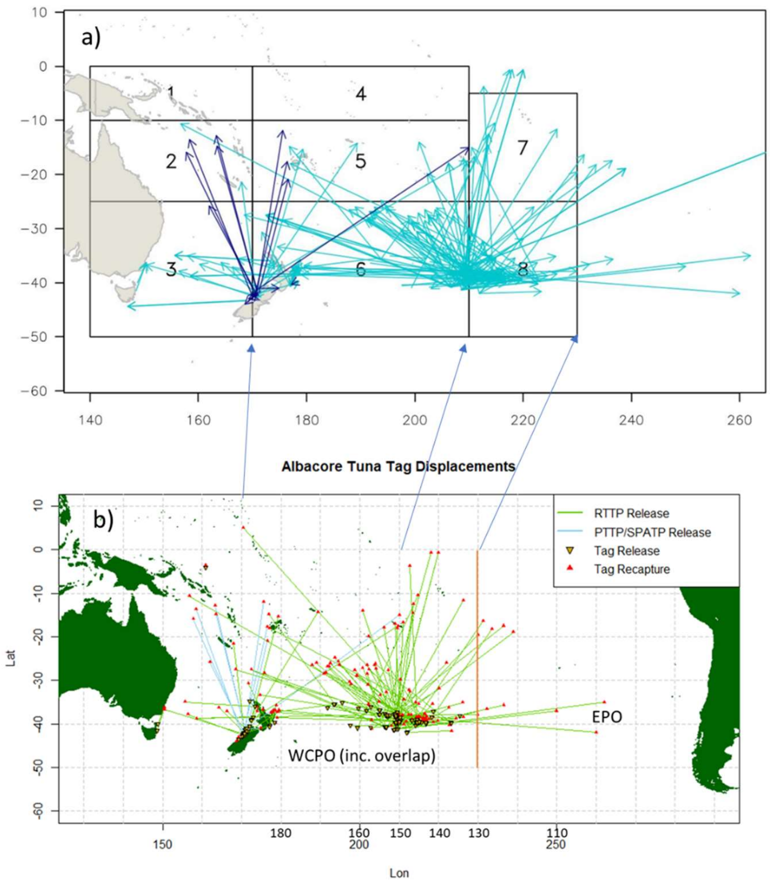

Figure 2. Maps of tag recapture displacements for south Pacific albacore overlayed on; a) the model region structure for the WCPO in the 2015 assessment, b) the entire south Pacific region, with red line at 130°W marking the eastern boundary of the overlap region between the WCPO and EPO.

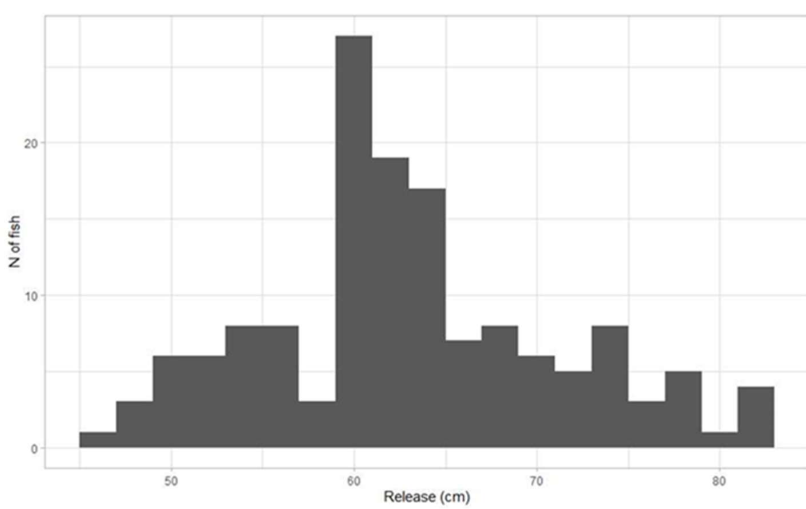

Figure 3. Length composition tagged albacore at release.

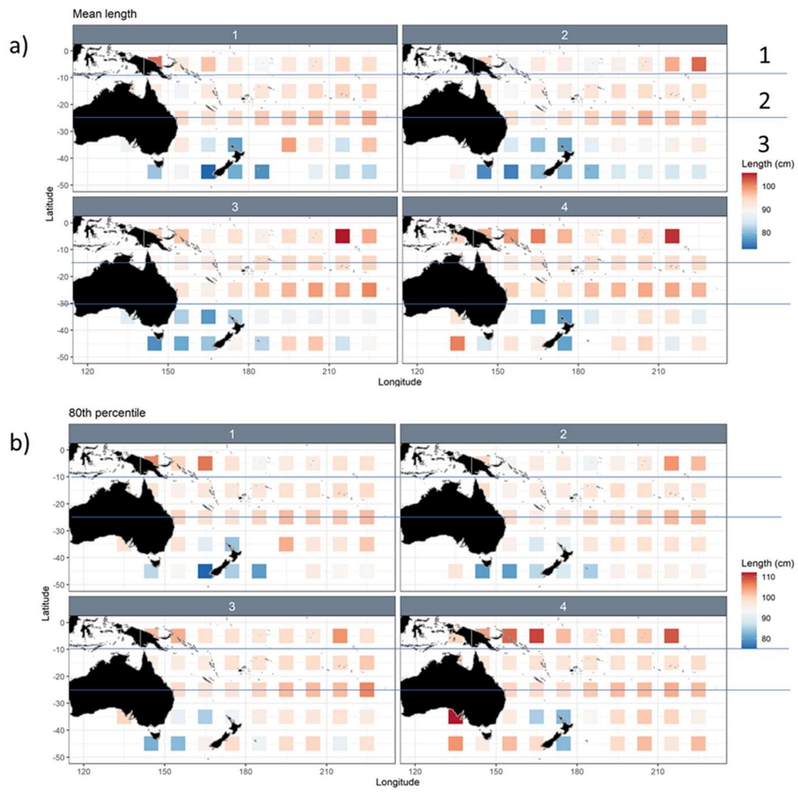

Figure 4. Spatial patterns in length composition of south Pacific albacore in the WCPO; a) mean length, b) 80th percentile length (i.e., length at which 80% of samples are below).

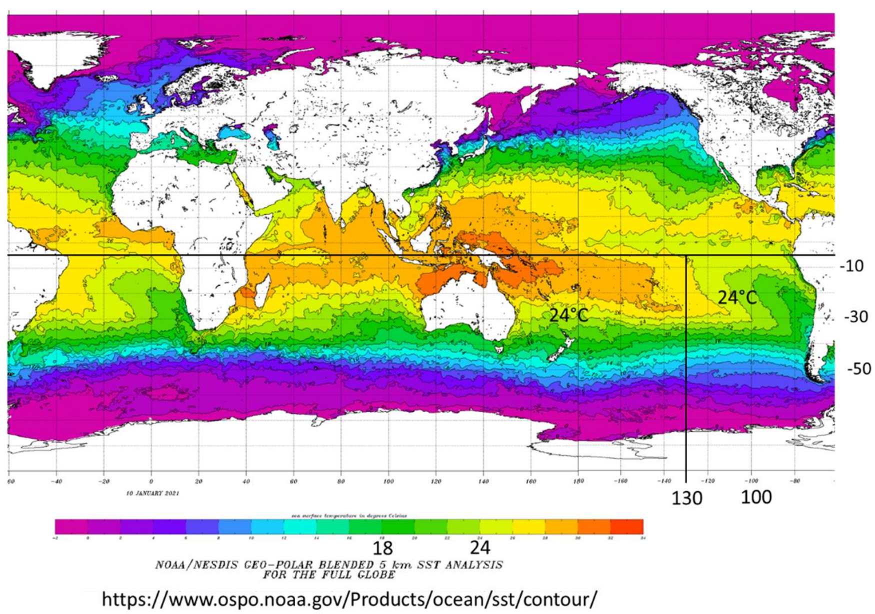

Figure 5. Example: Map of recent global SST variation showing indicative region of the 24°C isotherm. Updated available images at: https://www.ospo.noaa.gov/Products/ocean/sst/contour/index.html

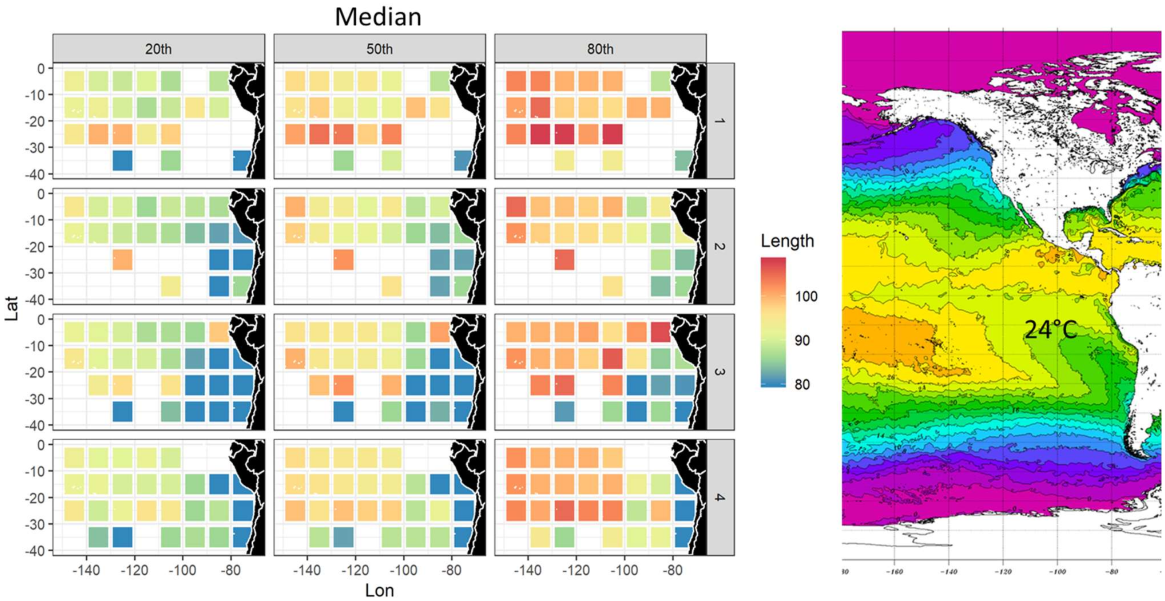

Figure 6. Spatial patterns in length composition of south Pacific albacore in the EPO, 20th, 50th and 80th percentile lengths (left) and (right) inset of relevant region from the indicative SST map in Figure 5.

a)

b)

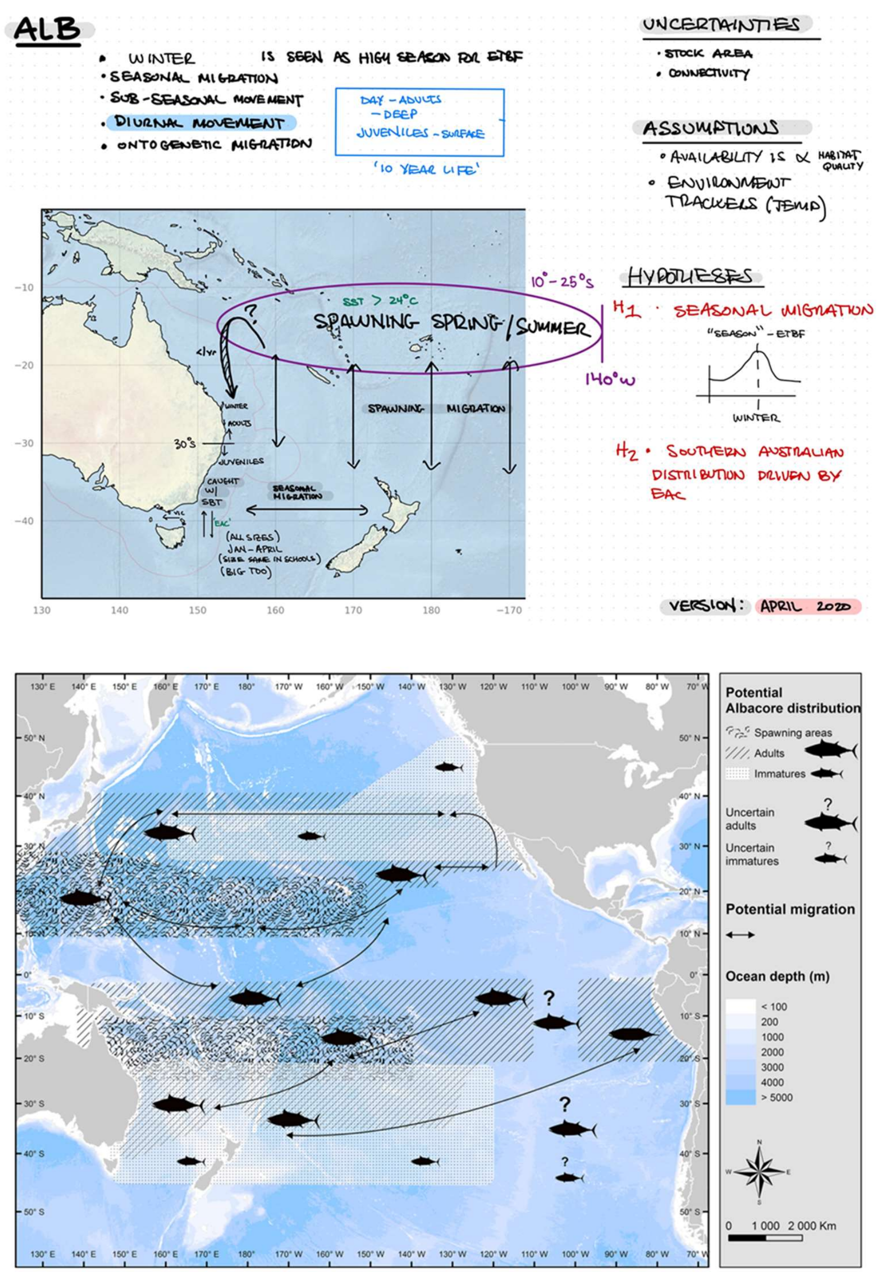

Figure 7. Conceptual diagrams of Pacific albacore life-history migratory dynamics, a) from informal CSIRO expert workshop (courtesy Jason Hartog, CSIRO, Australia), b) from the review by Nikolic et al. (2017), and c) spatial dynamics models from the paper by Senina et al. (2020).

c)

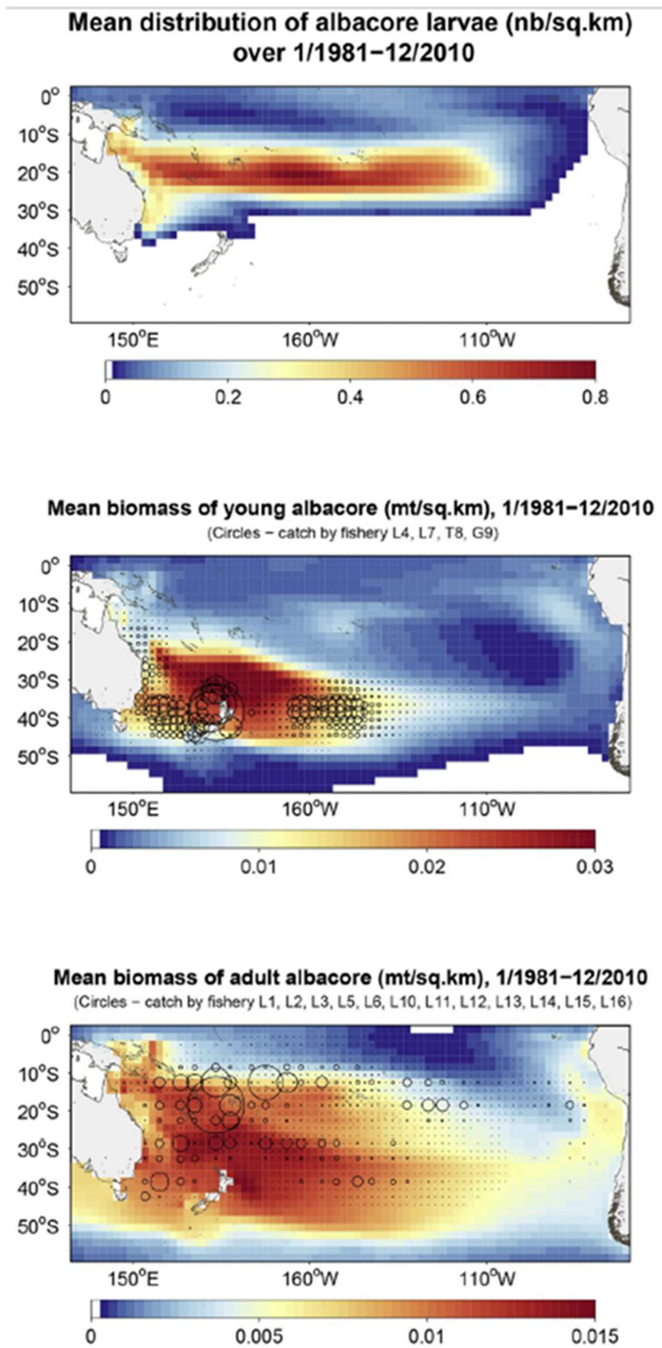

Fig. 7 continued.

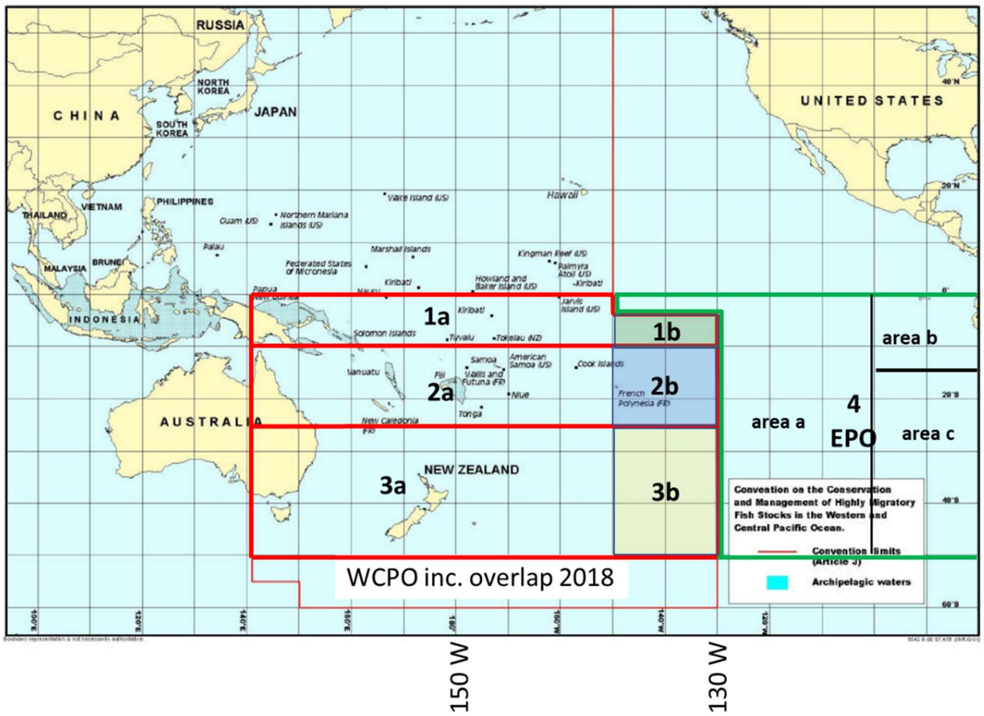

Figure 8. Map showing proposed model regions 1-4, and areas-as-fleets cells 1-3a, b for WCPO and areas 1, 2, and 3 for the EPO.

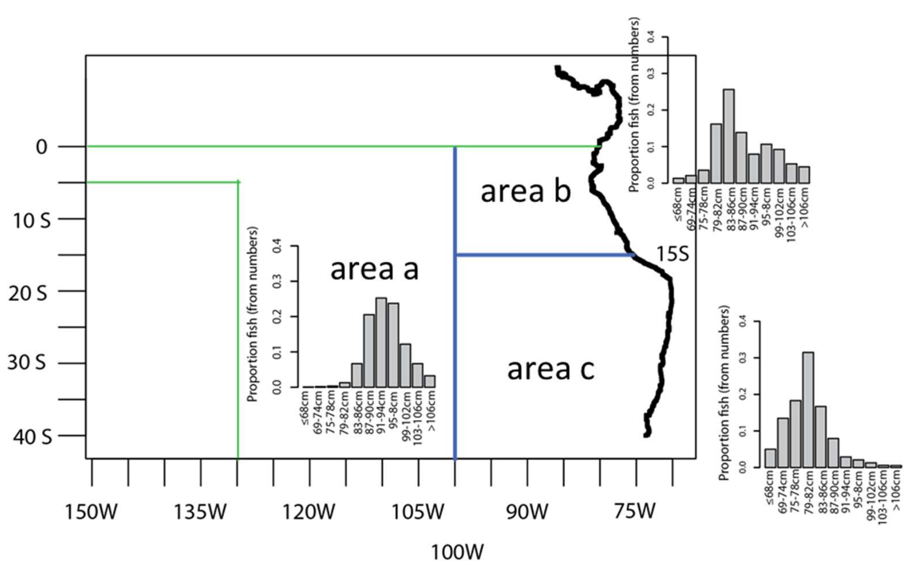

Figure 9. Proposed areas-as-fleets areas from the EPO tree analysis, with the length compositions for each area.

Table 1. Proposed fishery definitions for the 2021 south Pacific albacore assessment (index fisheries in grey). Model regions and fleet areas refer to Fig. 8

Fishery Number	Gear	Model Code-Fleets	Flags	Model region	Fleet area
1	LL	1-LL-DWFN	ALL	1	a
2	LL	2-LL-PICT	ALL	1	a
3	LL	3-LL-DWFN	ALL	2	a
4	LL	4-LL-PICT	ALL	2	a
5	LL	5-LL-AZ	AU/NZ	2	a
6	LL	6-LL-DWFN	ALL	3	a
7	LL	7-LL-PICT	ALL	3	a
8	LL	8-LL-AZ	AU/NZ	3	a
9	LL	9-LL-DWFN	All	1	b
10	LL	10-LL-PICT	All	1	b
11	LL	11-LL-DWFN	ALL	2	b
12	LL	12-LL-PICT	ALL	2	b
13	LL	13-LL-DWFN	ALL	3	b
14	LL	14-LL-PICT	ALL	3	b
15	TR	15-3a-All-TR	ALL	3	a
16	DN	16-3a-All-DN	ALL	3	a
17	DN	17-3b-All-DN	ALL	3	b
18	LL	18-LL-EPO1	ALL	4	a
19	LL	19-LL-EPO2	ALL	4	b
20	LL	20-LL-EPO3	ALL	4	c
21	TR	21-TR-EPO	ALL	4	a, b, c
22	LL	1-L-INDEX	INDEX	1	-
23	LL	2-L-INDEX	INDEX	2	-
24	LL	3-L-INDEX	INDEX	3	-
25	LL	4-L-INDEX	INDEX	4a	a*

LL = longline, TR = troll, DF=driftnet, PICT = Pacific, AU=Australia, NZ=New Zealand, AZ=Australia/New Zealand, EPO = Eastern Pacific Ocean, DWFN = Distant Water Fishing Nations