SPRFMO
South Pacific Regional Fisheries Management Organisation

11th MEETING OF THE SCIENTIFIC COMMITTEE

11 to 16 September 2023, Panama City, Panama

SC11 – Doc11

Patterns in species composition associated with targeting jack mackerel, redbait and/or alfonsino

Species Composition Task Team

1. Background

At the 10th annual SPRFMO Scientific Committee meeting, document SC10-Doc13 *Patterns in species composition associated with targeting jack mackerel, redbait and/or alfonsino* was presented. This paper was prepared in response to a request by the SPRFMO Commission during their 10th annual meeting (para 42 COMM10 Report). Most Members with data relevant to the Commission request, consented to their use for this analysis; however, the Russian federation consented to only one year (2021) of data, as opposed to all available historical data.

At the 10th SPRFMO Compliance and Technical Committee meeting, this compliance issue, initially raised at CTC9 (para 12 CTC9 Report), remained unresolved. Therefore, the 11th annual SPRFMO Commission, "*The Commission deferred the issue on alfonsino catches until the next annual meeting and tasked the SC with undertaking additional catch composition analyses incorporating the historic Russian catch data*" (COMM11-Report, para 37). Para 36 of the COMM11-Report records that "*the Commission agreed that additional analyses be sought from the SC's working group on Catch Composition and that Russia provide their historic catch data (2007-2022) to the SC for that purpose*".

This paper provides an update to SC10-Doc13, with the additional data from the Russian Federation. The methodologies used to evaluate these data are consistent with those presented last year.

2. Data released for analyses

There were eight members identified as having data relative to the analyses requested by the Commission (i.e., Chile, China, European Union, Faroe Islands, Korea, Peru, Russian Federation, and Vanuatu). Letters were sent to all Members requesting consent to use historical data (extending back to 2007) from the SPRFMO Convention Area, including: fishing activity, observer, VMS, and port inspection data. All Members, excepting Peru, provided consent to use the requested data for these analyses.

3. Data analysis

The Species Composition Task Group took a three-pronged approach to evaluate the species composition associated with fishing activities targeting jack mackerel, redbait, and alfonsino:

1. develop a suite of descriptive metrics and data summaries to characterise general patterns from the data;
2. use a hierarchical clustering approach to identify major fishing 'modes'; and
3. develop a statistical approach (generalised additive model) to quantify relationships between a suite of explanatory variables and jack mackerel catch rates.

3.1. Fishing activity data

The fishing activity data contains information from seven Members having fished for jack mackerel between 2007 and 2021 (Table 1). There was limited data for 2007, from only one Member, therefore, that year was omitted. Similarly, there was very limited data from 2020 due to the COVID-19 pandemic, so that year was also omitted. Therefore, the data evaluated are from 2008-2019, 2021-2022.

Table 1: Fishing activity records available for analyses, by Member and year.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2021	2022
CHL	-	-	-	-	X	X	X	X	X	X	X	X	-	-
CHN	-	X	X	X	X	X	X	X	X	X	X	X	-	-
EU	X	X	X	X	-	X	X	X	X	X	X	X	X	X
FRO	-	-	X	-	-	-	-	-	-	-	-	-	-	-
KOR	X	X	X	X	X	X	X	X	X	X	X	X	-	-
PER	-	-	-	-	X	X	X	-	-	-	-	-	-	-
RUS	-	-	-	-	-	-	-	X	-	X	X	X	X	X
VUT	X	X	X	X	X	X	X	X	X	X	-	-	-	-
Records	4 369	9 412	6 698	3 425	1 812	1 495	1 733	4 539	4 949	2 235	2 092	1 932	1 830	2 201

The proportion of the total catch composed of jack mackerel, within a fishing event, varied over time but was on average over 95% in most years (median value = 1 in most years), and in some years, close to 100% (Figure 1). 2021 and 2022 appear to be exceptions, as in 2021 the mean proportion of jack mackerel in catches was 69% (median 83%) and in 2022, 66% (median 70%). In almost all years, there were fishing events with very low proportions of jack mackerel (e.g., 0), although they were not very common.

There were differences in the proportion of jack mackerel caught by Member. For example, China caught almost exclusively jack mackerel whereas the vessels from Vanuatu (2008-2009 and 2015) and Chile operating in the SPRFMO area had lower proportions of jack mackerel in the total catch (Figure 1). The European Union, Korea, and the Russian Federation's data demonstrates greater variability in the proportion of jack mackerel throughout their time series, noting that the data from all Members generally indicates a very high proportion of jack mackerel when that is the target species.

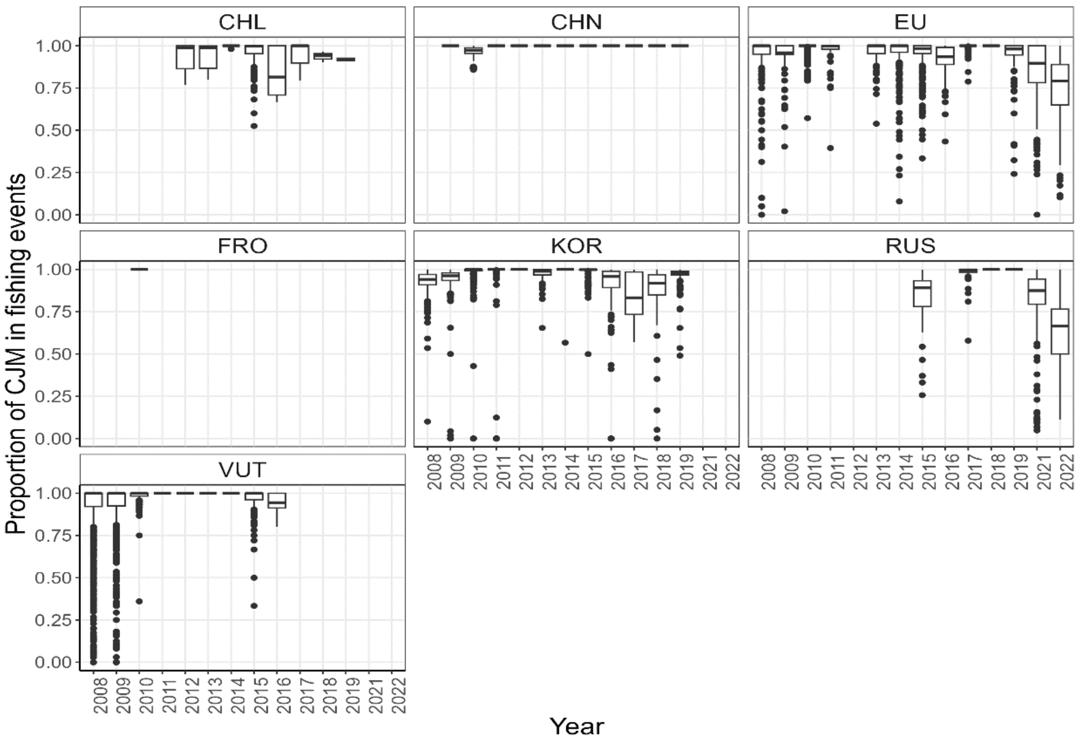


Figure 1: Proportion of jack mackerel in the total catch, by fishing event and member, over the years.

The fishing events where the jack mackerel proportion was lower than 0.5 (less than 3% of all recorded events), the catch composition was generally composed of chub mackerel (MAS), southern rays bream (BRU), blue fathead (UBA), and more recently redbait (EMM) and alfonsino (BYS), with chub mackerel representing the vast majority of these catches (Figure 2). It should be noted that some Members have not reported any bycatch, other than chub mackerel, throughout the time series evaluated. Maps illustrating the spatial and temporal distribution of the main species harvested during fishing events targeting jack mackerel, alfonsino, or redbait are included in the Supplemental Figures (SF1-SF7), for refence.

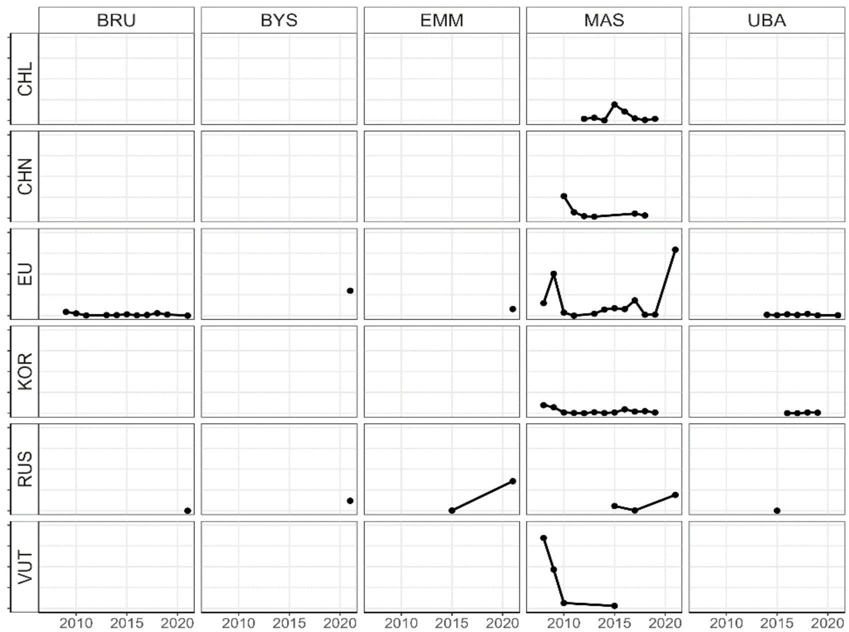


Figure 2: Time series of bycatch trends, for top five bycatch species across all fleets and years, by flag and species (southern rays bream (BRU), splendid alfonsino (BYS), redbait (EMM), chub mackerel (MAS), and blue fathead (UBA). All panels are scaled from 0- 10,000 tonnes.

Overall, fishing generally took place at depths between of 22-60 m (25th-75th percentiles) across years; however, gear depth information was not available for all fishing events. Typically, jack mackerel was caught within the upper layers of the water column, leaving between 3000-4000 m between the position of the gear to the seafloor. However, there were a few hauls where this distance was less than a few hundred meters (Figure 3).

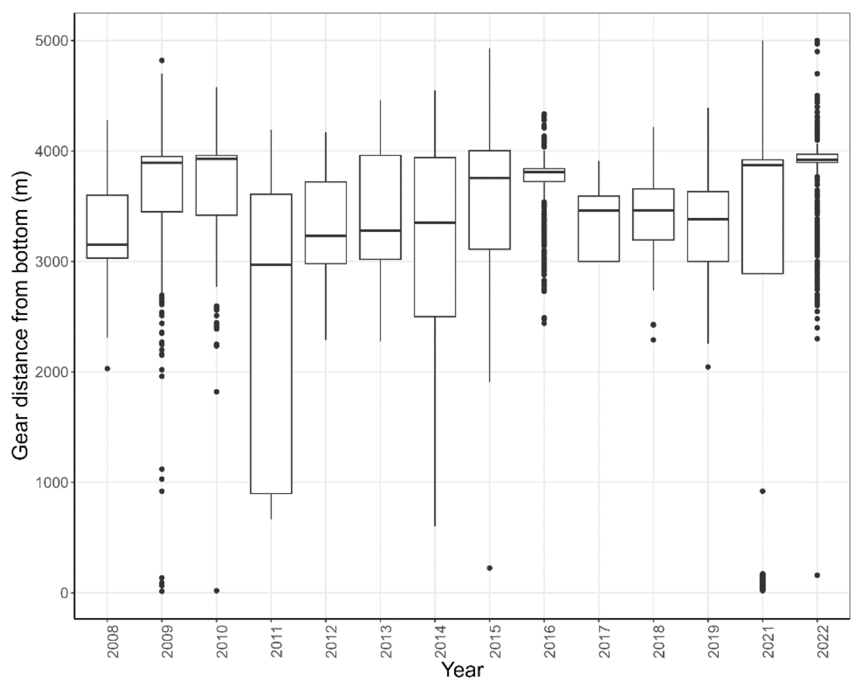


Figure 3: Distance between the fishing gear and the seafloor (m), across years. Note: gear depth is not available for all fishing events.

The spatial distribution of the jack mackerel fishery has changed substantially over the years. In the early part of the time-series (i.e., 2008-2012), the fishery extended all the way to 240° west with a latitudinal center of approximately 40°S (Figure 4). In the years following, catches were taken closer to the eastern border of the SPRFMO area and were distributed further north. In the past few years fishing has taken place north of 20° S; this distribution of fishing activity has generally been attributed to La Niña conditions.

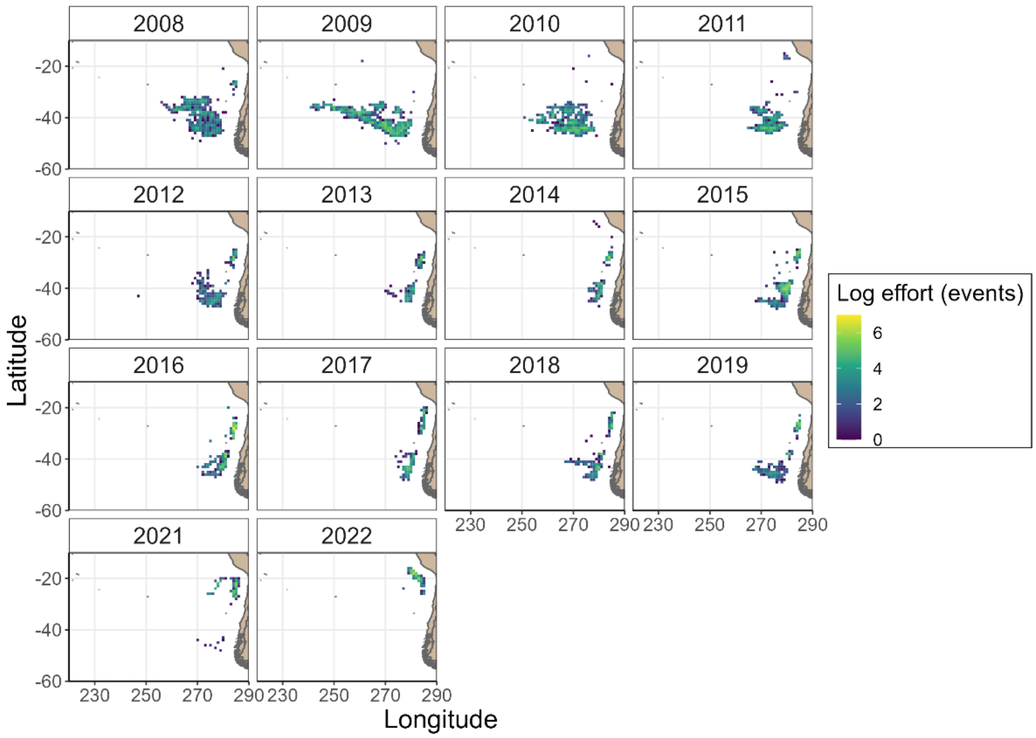


Figure 4: Distribution of effort from the jack mackerel fishery between 2008 and 2022.

Another metric explored last year, was the grouping of sequential fishing events occurring in a similar area within a relatively small temporal window. The assumption behind this exploration was that if jack mackerel fishing is productive, a vessel may be more inclined to remain in the same area to continue fishing. On the contrary, if fishing is poor (characterized by low proportion of jack mackerel or low catch rates), a vessel may move to a new area with hopes of improving catch rates. To explore this idea, fishing events were grouped into clusters (or sequential) fishing activities. If a vessel conducted sequential fishing events within 24 hours and 100 km of each other, they were considered part of the same fishing event grouping. If sequential fishing events occurred outside of those spatial and temporal parameters, they were considered separate fishing event groups. There was no limit on the number of fishing events that could be grouped together.

In total, all years and vessels combined, there were 6,375 unique fishing events groups identified, using the approach above. The median number of sequential within group fishing events was 2 (μ=4), while the maximum was 53. For all event groupings, the target species of the grouped sequential hauls was the same, meaning there was no target switching observed within sequential fishing event groups. Figure 5 shows the distribution of the number of within group events, by target species (note the different scales of the axes).

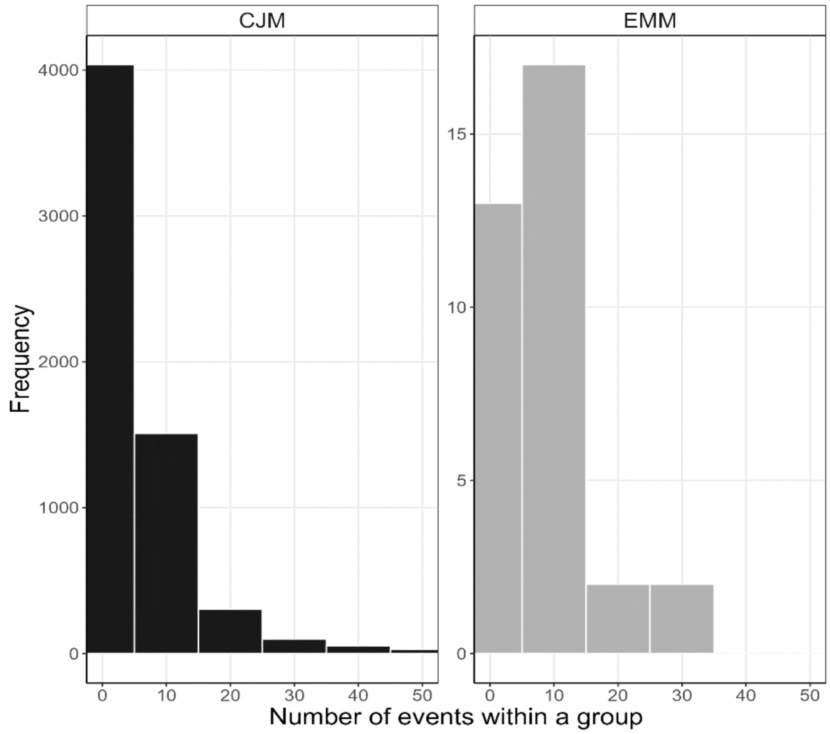


Figure 5. Distribution of within group fishing events, for sequential events, by target species.

For simplicity, we assigned these fishing events groups into one of three categories based on the number of sequential fishing events in the group, i.e., low (1-2 events), medium (3-5 events), and high (5+ events). Figure 6 illustrates the proportion of jack mackerel from each of the fishing group categories, by year. This figure shows that through most of the time series, the proportion of jack mackerel is similar among the sequential event groups. In 2021 and 2022, however, there is considerably more variability in the proportion of jack mackerel in the catches and in 2022, the proportion of jack mackerel was lower for the category with a high number of sequential hauls, indicating a potential shift in target species (as corroborated by the presence of EMM targeting in the fishing activity data).

We further explored the fishing events that encountered alfonsino or redbait, to specifically assess the species composition of those events (Figure SF8). We grouped the event-level catches by year, week, and target species to see the progression of catches, in time. These events are associated primarily with redbait and alfonsino catches, with some of the events catching relatively small amounts of jack mackerel, chub mackerel, and mackerel scad *Decapterus macarellus* (MSD).

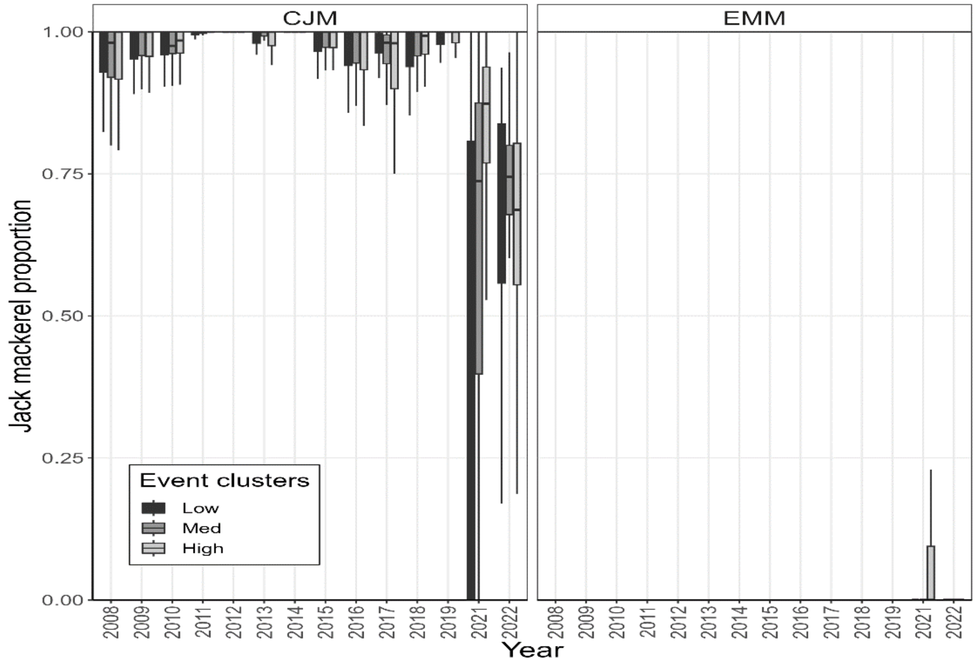


Figure 6. Distribution of the proportion of jack mackerel in the catch, by event group category, year, and target species (outliers not shown).

In addition to the proportion of jack mackerel, we were interested in the total amount of jack mackerel harvested by the different sequential fishing event groupings. Figure 7 shows that vessels tended to remain in a similar area to conduct sequential hauls when catch rates were relatively high. On average, the clusters with fewer events were associated with lower catch rates, but with considerable overlap with the other grouping categories.

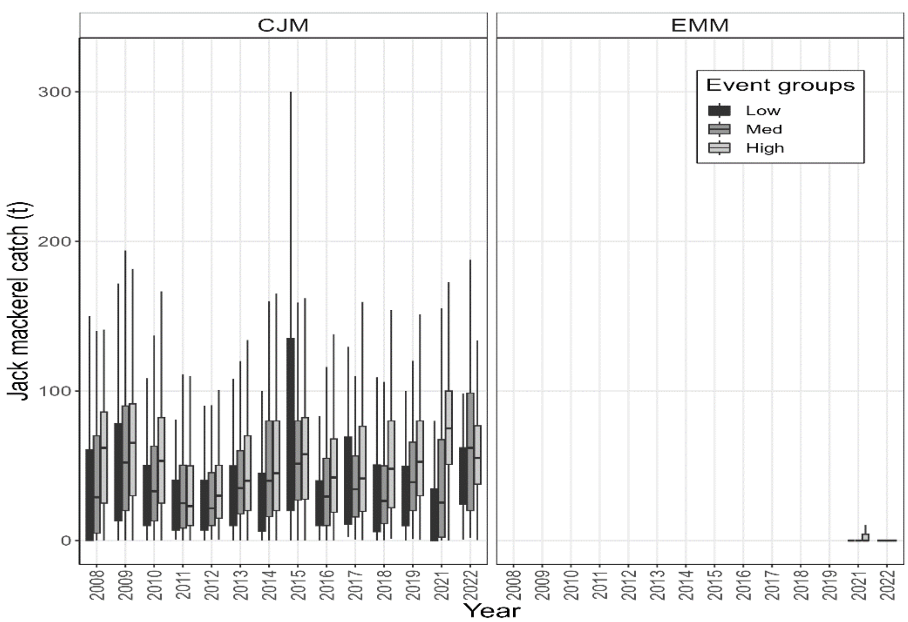


Figure 7. Distribution of jack mackerel catch from the three sequential event grouping categories, by year and target species.

With respect to species other than jack mackerel, catch rates have generally been low (Figure 8). In recent years, however, there has been a notable uptick in the amount of non-jack mackerel catches caught while targeting jack mackerel. Figure 7 also shows the distribution of non-jack mackerel catches while targeting redbait (EMM), which should not be surprising, as jack mackerel is not the main target of those fishing events.

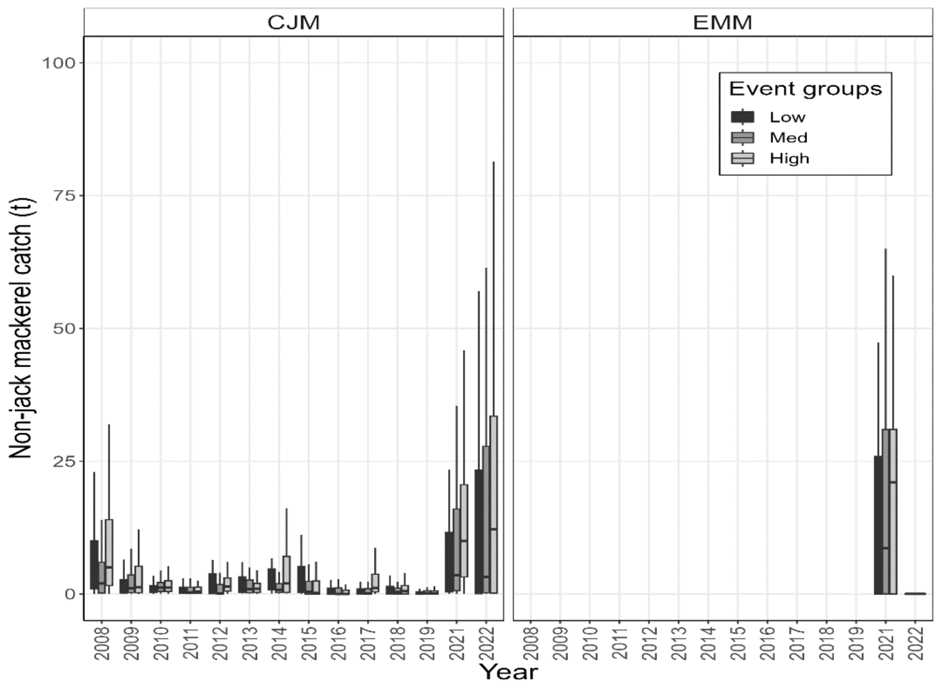


Figure 8. Distribution of event level non-jack mackerel catches by sequential event groupings, year, and target species.

3.2. Hierarchical clustering

To evaluate the species composition, at the event level (i.e., haul-by-haul), a hierarchical clustering approach was taken. The haul-level catches of all species reported were converted from biomass estimates to a percentage of total catch, from that fishing event. These data were then converted into a dissimilarity matrix using the Bray-Curtis method (Bray and Curtis, 1957) and the R *vegan* package (Oksanen et al., 2022),

$$S_{jk} = 100 \frac{\sum_{i=1}^{p} 2\min(y_{ij}, y_{ik})}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}$$

where y_{ij} represents the catch percentage of the *ith* fishing event (*i* = 1,2,...,*p*) for *jth* species (*j*= 1,2,...,*n*).

The dissimilarity matrix was then squared and clustered, hierarchically, using the Ward's minimum variance method, which is based on a sum-of-squares criterion (i.e., method='ward.D2' in the R *hclust* function) (Murtagh and Legendre, 2014). To determine the optimal number of cluster groupings, the output from the clustering algorithm was plotted as a dendrogram to visually identify event clustering. In addition, the mean silhouette statistics were evaluated to quantitatively assess the individual and overall cluster groupings, with the number of groupings based on the clustering with the highest mean value (Figure SF9).

The dendrogram (Figure 9) was visually assessed with group partitions ranging from 2-10. Based on these diagnostics, splitting the fishing events into four groups emerged as the most reasonable option.

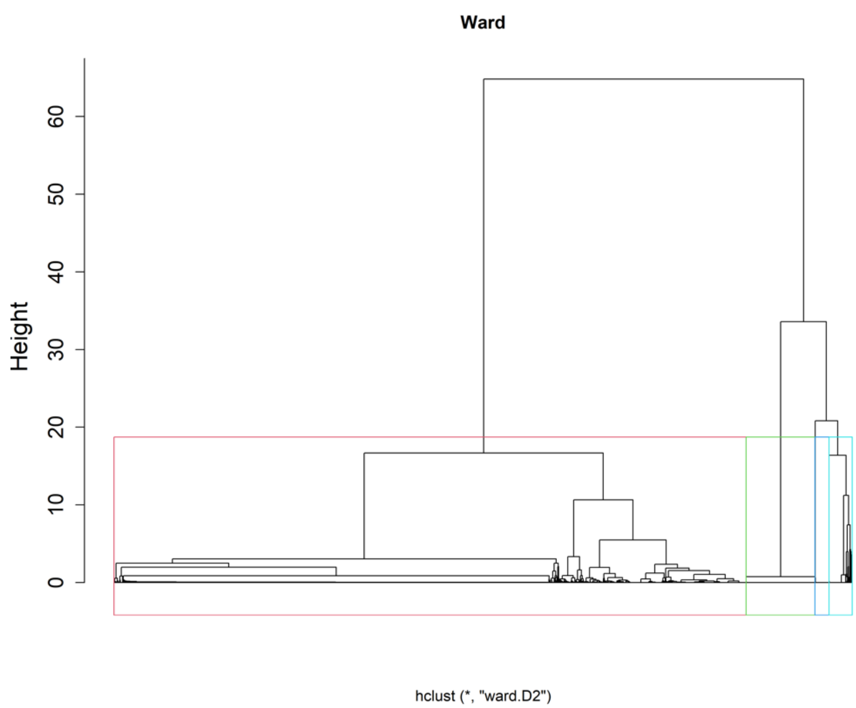


Figure 9: Dendrogram from hierarchical clustering approach, highlighting the partitions associated with splitting the fishing events into four groupings.

The species composition of the four clusters, in order of grouping cluster, was comprised of 1: almost entirely jack mackerel (CJM); 2: almost exclusively chub mackerel (MAS); 3: a mixture of alfonsino (BYS), redbait (EMM/EMT), blue fathead *Cubiceps caeruleus* (UBA), southern rays bream *Brama australis* (BRU), with small amounts of jack mackerel, chub mackerel, and jumbo squid (GIS); and 4: unclassified marine fishes (MZZ) (Figure 10).

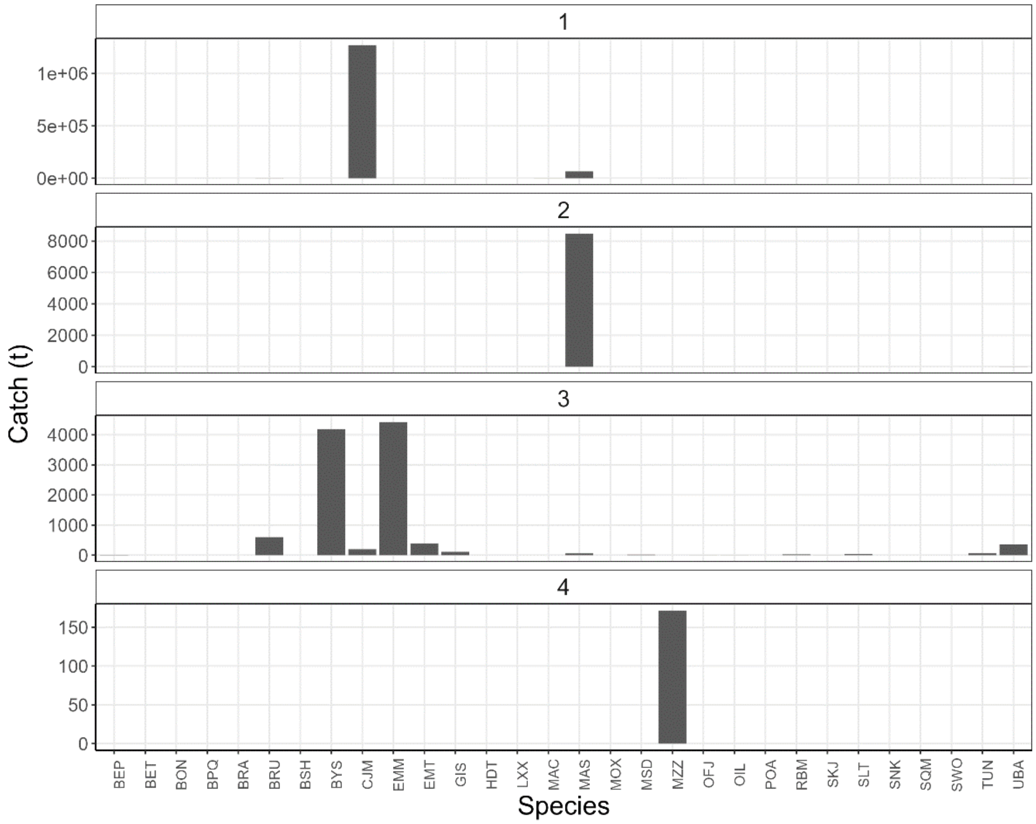


Figure 10: Catch composition, by cluster, aggregated across all years and fleets.

The trend in cluster association and catch composition was assessed by looking at the distribution of events, by cluster, flag, and year. The jack mackerel (1) and chub mackerel (2) clusters are by far the dominant modes of species composition. The alfonsino/redbait (3) cluster appears to be a more recent phenomenon (Figure 11) and is largely characterised by activity with species composition and spatial distribution that differs from fishing activity targeting jack mackerel (Figure 12). Cluster 3 activities are generally fished at deeper gear depths than fishing events targeting and catching jack mackerel (Figure 13) and are concentrated along a region of seamounts. Cluster 4, the MZZ cluster, is suggestive of a potential data quality artefact, given it is largely associated with a single fleet for a discrete period (2009, 2010), and has substantial spatial overlap with the main jack mackerel fishing grounds.

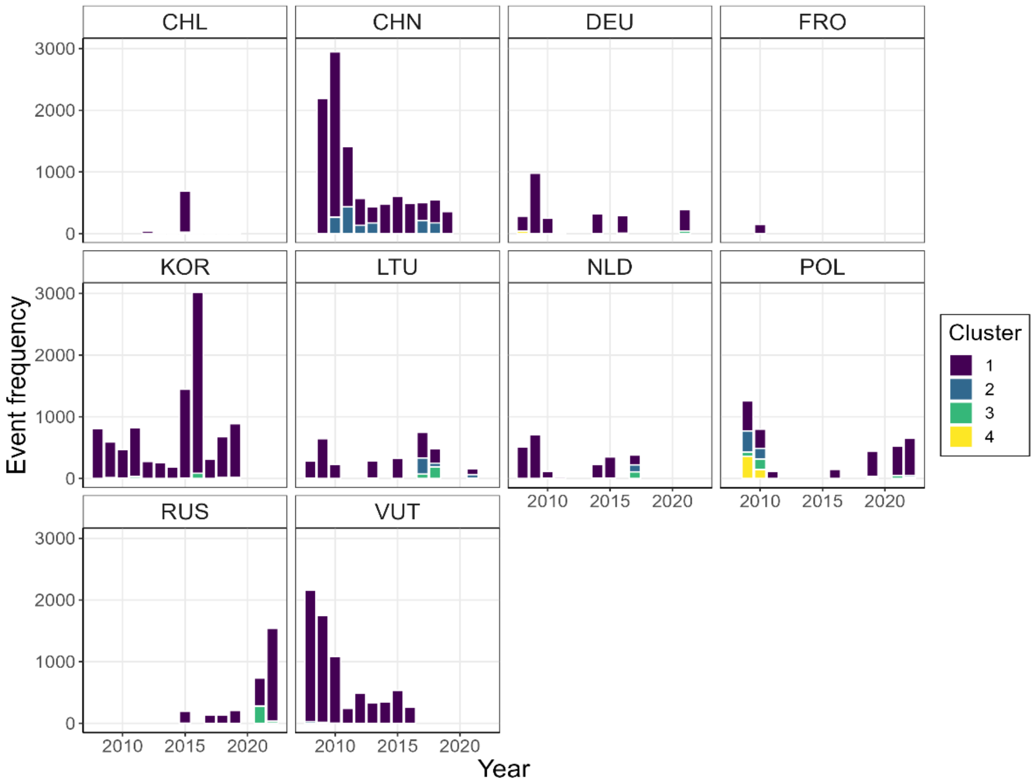


Figure 11: Frequency of cluster association by flag and year.

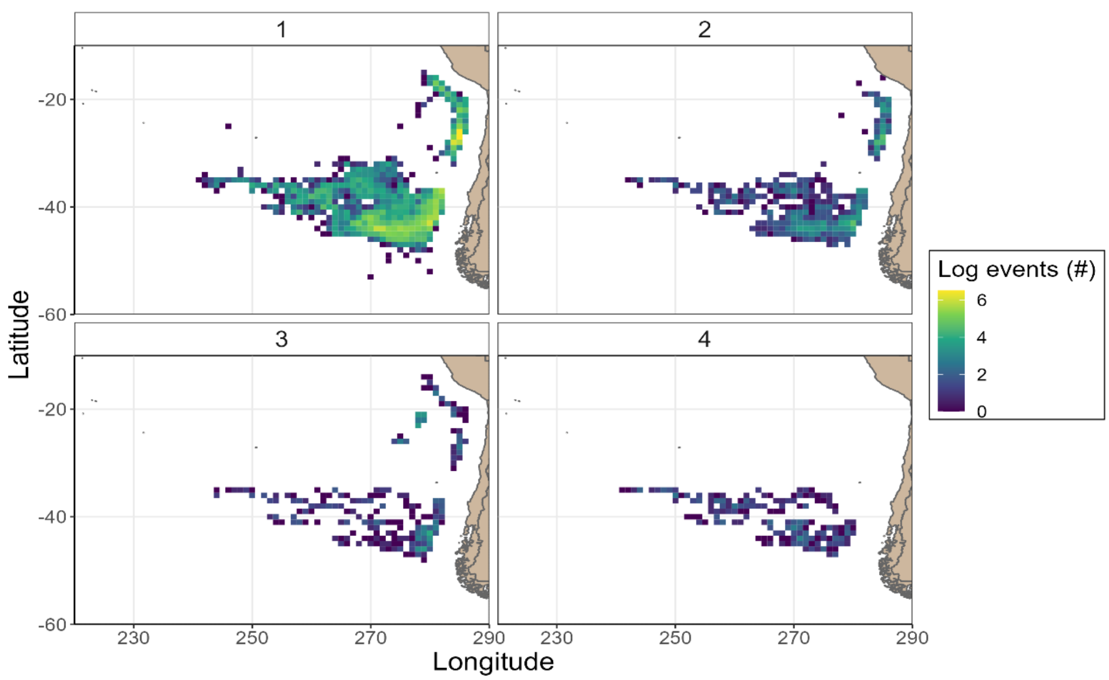


Figure 12: Distribution of fishing events (represented as the log number of fishing sets), by cluster association, across all flags and years.

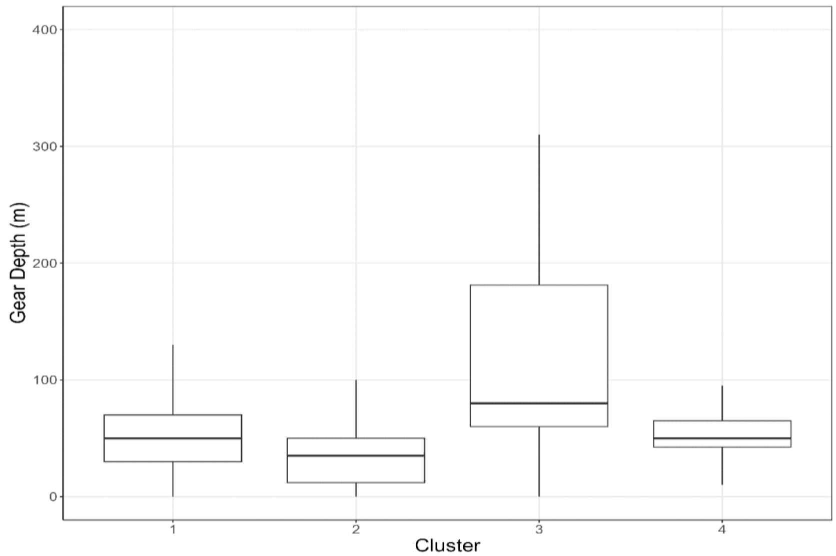


Figure 13: Distribution of gear depth (m), by cluster groupings.

3.3. Generalised additive modelling

In SC10-Doc13, two different approaches were taken to model jack mackerel catches using GAMs. The two models provided similar results, and therefore, this year we have opted to present just one of the models.

We used a Tweedie generalised additive modelling (GAM) approach to model jack mackerel catch rate (t) at the haul-level as a function of covariates predicted to influence the catch rates. The Tweedie is a flexible distribution suitable for non-negative continuous data with a density of observations at zero. Specifically, jack mackerel catch from fishing event *i* (C_i) was modelled as,

$C_i \sim Tw_p(\mu_i, \varphi)$

where

$\mu_i = \eta_i$

$$log(\eta_i) = \beta_0 + \beta_1 \text{Year}_i + \beta_2 \text{GearDepth}_i + s(\text{Lon}_i, \text{Lat}_i) + \text{offset}(log(\text{TotCatch}_i)) + \varepsilon_i$$

and η_i is the linear predictor for the observed jack mackerel, at the haul-level, using a log-link function. Here, β_0 is the global intercept, β_1 is the year effect (year is treated as a factor); β_2 is the fixed effect associated with gear depth (m); *s* represents an additive smooth effect for the spatial location of the catch; and an offset term of the log of the total catch (plus a small constant). The model included an observation-level random effect ε_i. The variance of C_i is assumed to be a function of the estimated dispersion φ and power *p* parameters (see Jorgensen, 1997 and Bonat and Kokonendji, 2017 for details).

$V(C_i) = \varphi \mu^p{}_i$

We fit the GAM using the R package *mgcv* (Wood and Wood, 2015).

The GAM model suggested that all covariates included in the model were significant in explaining variability in jack mackerel catches. Generally, jack mackerel catches decreased with the depth of the fishing gear, was variable through the years, and showed a spatial pattern that highlighted the areas of higher productivity and the peripheral areas demonstrating lower catches (Figure 14).

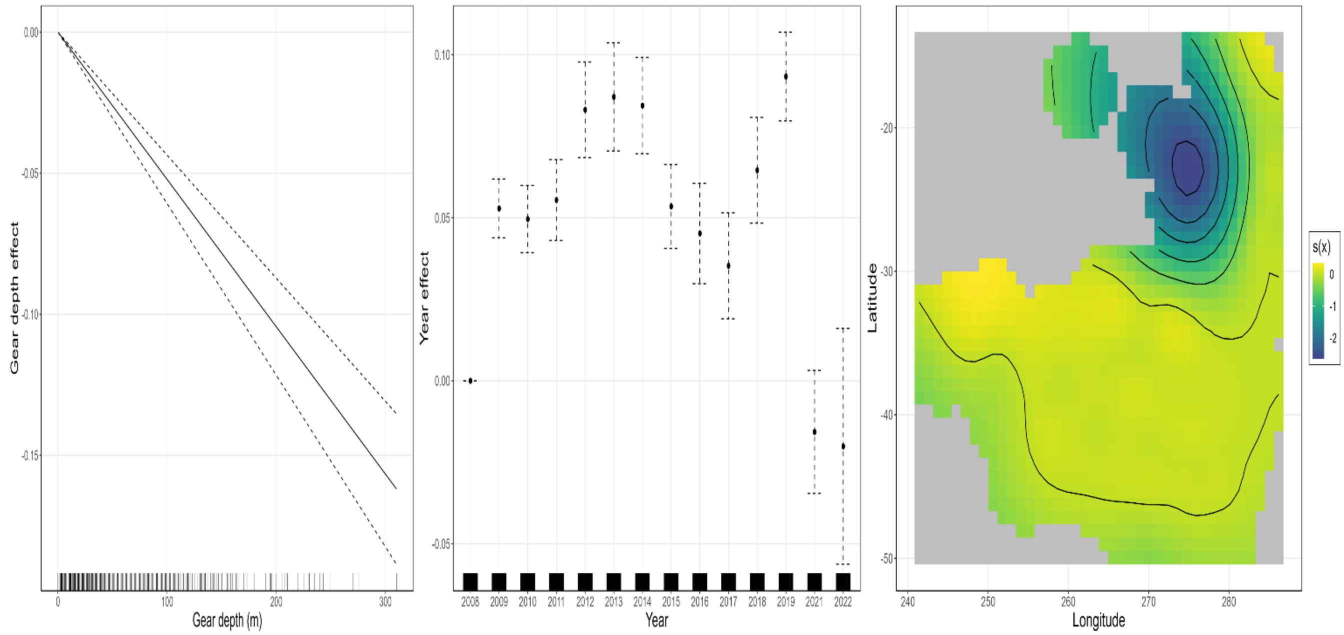


Figure 14: Gear depth effect plotted against the range of depths (m) observed in the data (left); the year effect (center); and spatial effects estimated from the GAM (right).

The standardized residuals (observed catch minus the predicted value from the GAM) show reasonably good predictions throughout the main range of the jack mackerel fishery, with large residuals (positive and negative) observed along the fringe areas (Figure 15). The area along the seamounts where redbait and alfonsino fishing has occurred show large negative residuals with some areas farther north showing large positive residuals. The large positive residuals are from unusually high catches of jack mackerel observed between 2009 and 2010.

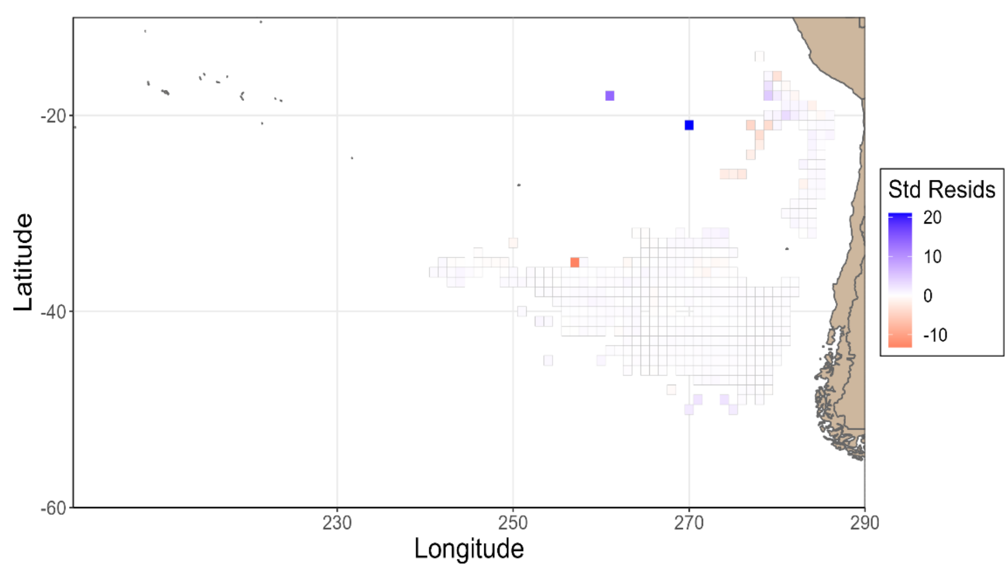


Figure 15: Median standardized residuals, by 1x1 degree spatial blocks, from the Tweedie GAM.

4. Conclusions

1. In total four different modes of fishing have been identified: (1) almost exclusively jack mackerel (CJM); (2) almost exclusively chub mackerel (MAS); (3) a mixture of alfonsino (BYS), redbait (EMM/EMT), blue fathead (UBA), southern rays bream (BRU), with small amounts of jack mackerel (CJM), chub mackerel (MAS), and jumbo squid (GIS); and (4) unclassified marine fishes (MZZ).
2. Fishing activities associated with chub mackerel catches are fairly common and are exclusively associated with a target species of jack mackerel (CJM). It is unclear whether fishers are targeting chub mackerel or whether the spatial and temporal overlap of the two species is such that distinguishing one from the other prior to setting is challenging.
3. Fishing activities associated with cluster 3 (alfonsino/redbait) were generally associated with deeper fishing depths, a spatial distribution over seamounts, and reduced jack mackerel catches. These activities have been associated with a target species other than jack mackerel (i.e., redbait).
4. The fishery generally considered a jack mackerel fishery overlaps with the chub mackerel distribution and the chub mackerel resource should be monitored given the incidental catches.
5. The characteristics of fishing activities associated with alfonsino and redbait catches are notably different from those associated with jack mackerel fishing. Clearly the intent for these operations is to target those species rather than them being incidental catches as part of the jack mackerel fishery.

5. Recommendations for the SC

This paper shows that the jack mackerel fishery has incidental catches of chub mackerel that should be monitored. In addition, the Commission should be aware that there are targeted fishing activities in the SPRFMO Convention Area that are unrelated to practices targeting jack mackerel (and chub mackerel). These activities fall outside of existing Conservation and Management Measures (CMMs).

As discussed last year during SC10 and COMM11, a “fishery” lacks a clear definition in the SPRFMO Convention, nor is it well defined within our CMMs. Similarly, there are minimal provisions in most of the CMMs (excepting for bottom fishing) with regards to bycatch or non-target/non-quota managed species. This paper highlights the need to improve upon those provisions in the existing CMMs and to perhaps revisit CMM 13 to clarify the conditions under which a fishery is a new and exploratory fishery and under what conditions fishing activities outside of those explicitly managed through quotas (or effort limits) are permitted within SPRFMO.

Stocks affected by the current fishing practices should be considered for developing future stock assessments, even if data-limited. We recommend that the SC consider prioritizing the species of interest, similar to the tiered system developed for deepwater species. Workplan tasking to address those needs would be appropriate, and specifics regarding chub mackerel catches and stock status should be pursued.

References

Bonat, W. H. and Kokonendji, C. C. (2017). Flexible Tweedie regression models for continuous data. *Journal of Statistical Computation and Simulation*, 87(11):2138–2152.

Bray, J. R. and Curtis, J. T. (1957). An ordination of the upland forest communities of southern Wisconsin. *Ecological monographs*, 27(4):326–349.

Jorgensen, B. (1997). *The theory of dispersion models*. CRC Press.

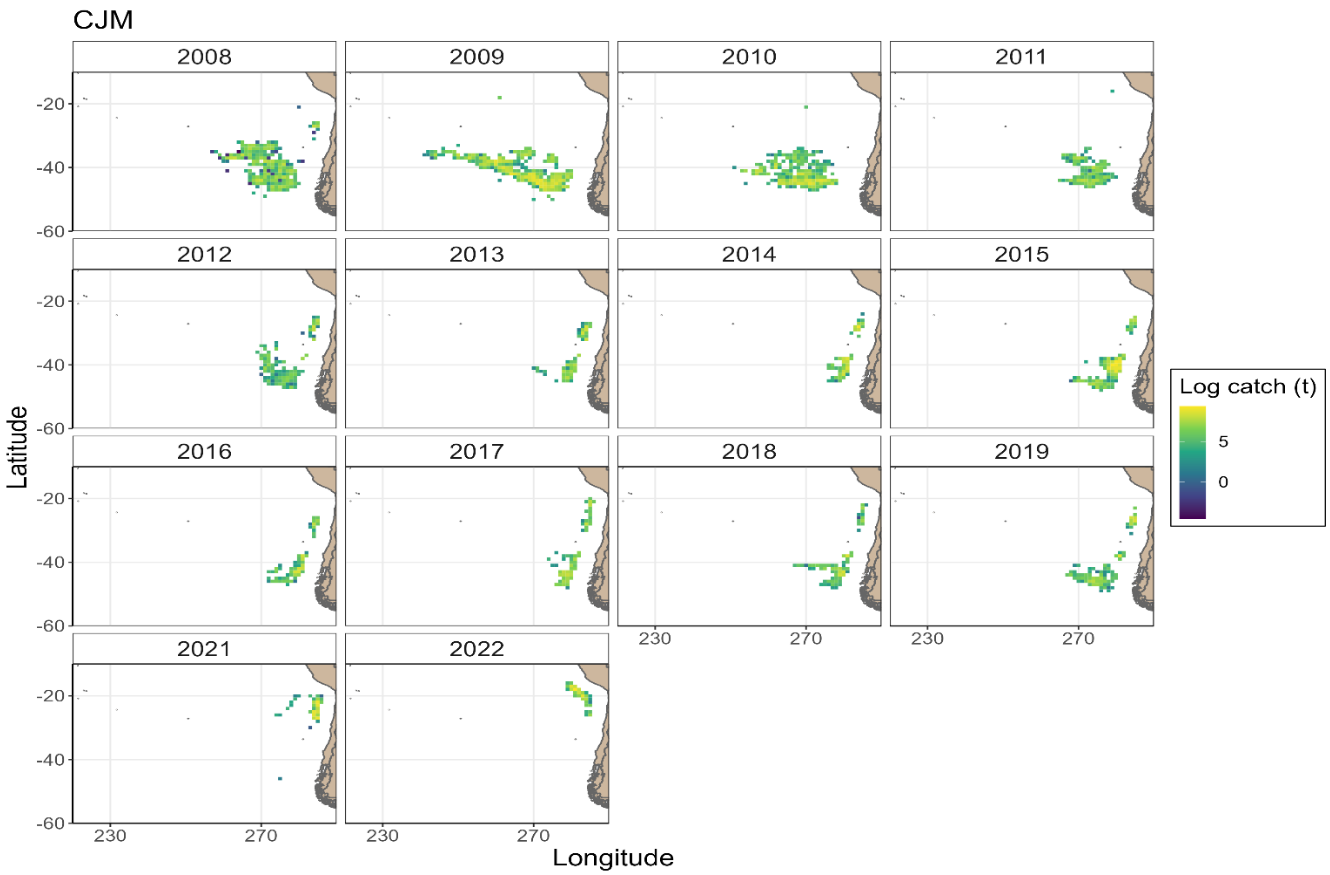
Murtagh, F. and Legendre, P. (2014). Ward's hierarchical agglomerative clustering method: which algorithms implement Ward's criterion? *Journal of classification*, 31(3):274–295.

Oksanen, J., Simpson, G. L., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R., Solymos, P., Stevens, M. H. H., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., De Caceres, M., Durand, S., Evangelista, H. B. A., FitzJohn, R., Friendly, M., Furneaux, B., Hannigan, G., Hill, M. O., Lahti, L., McGlinn, D., Ouellette, M.-H., Ribeiro Cunha, E., Smith, T., Stier, A., Ter Braak, C. J., and Weedon, J. (2022). *vegan: Community Ecology Package*. R package version 2.6-2.

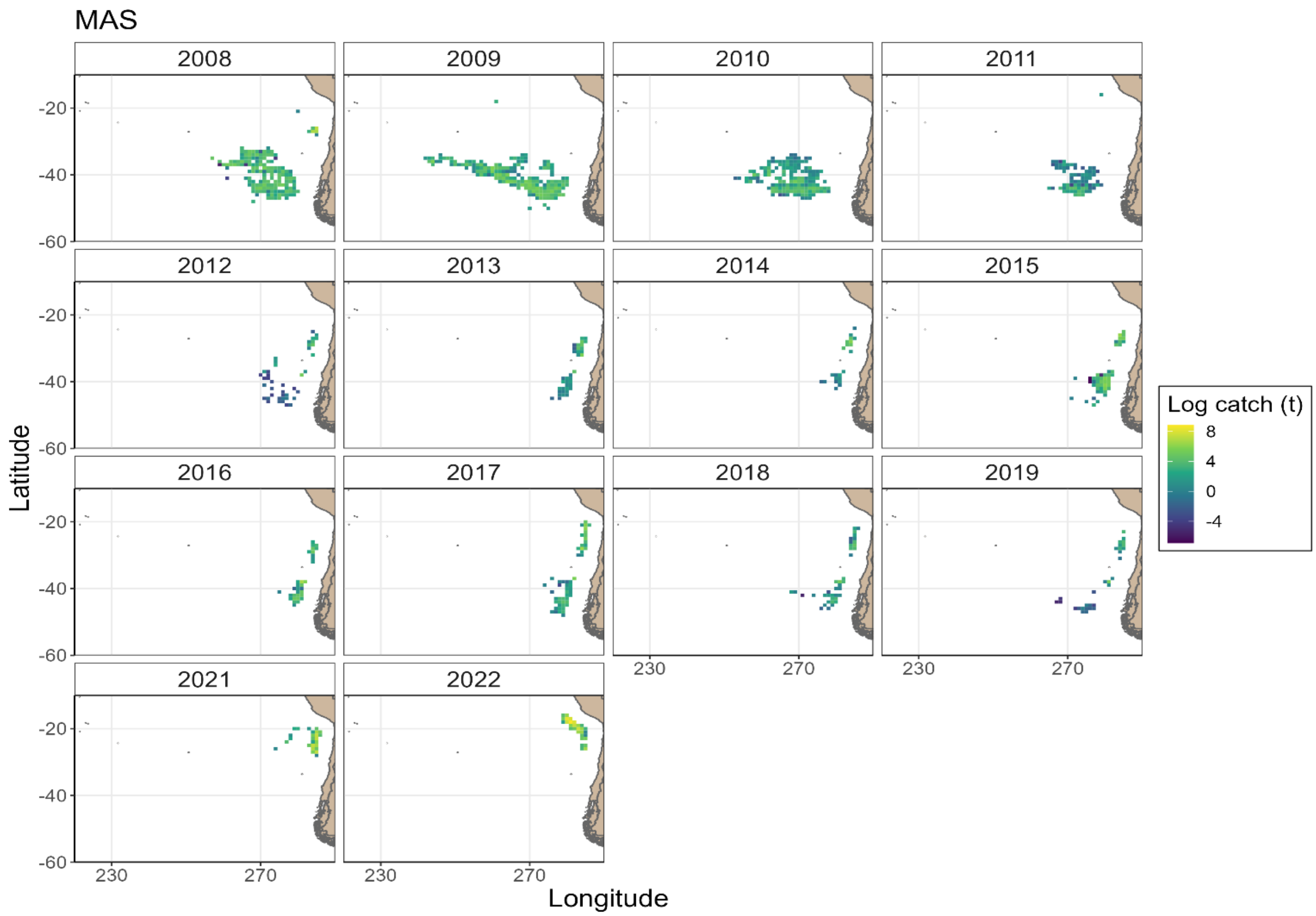
Wood, S. and Wood, M. S. (2015). Package 'mgcv'. *R package version*, 1(29):729.

Supplemental figures

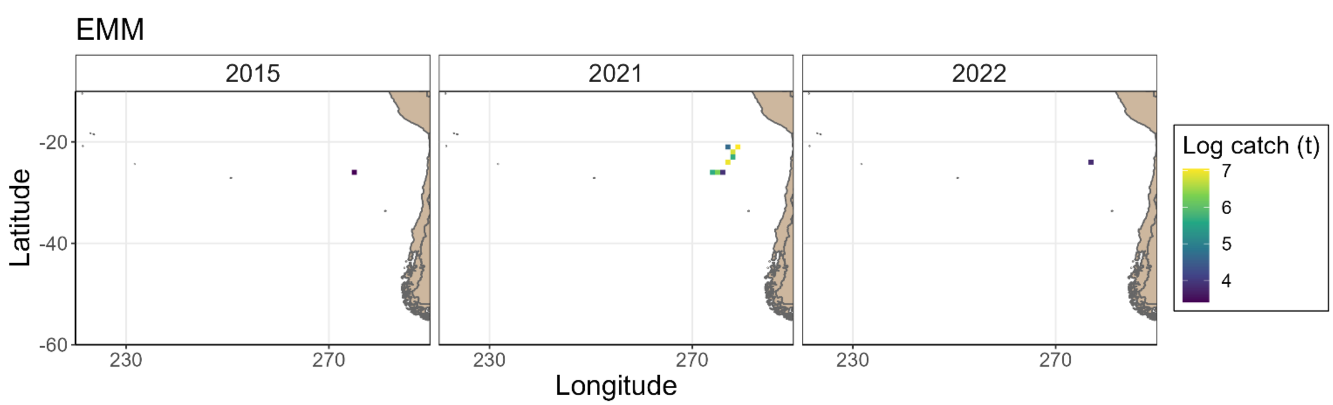
Figure SF1-SF6. Spatial and temporal distribution of the main harvested species when targeting jack mackerel (CJM) or redbait (EMM).



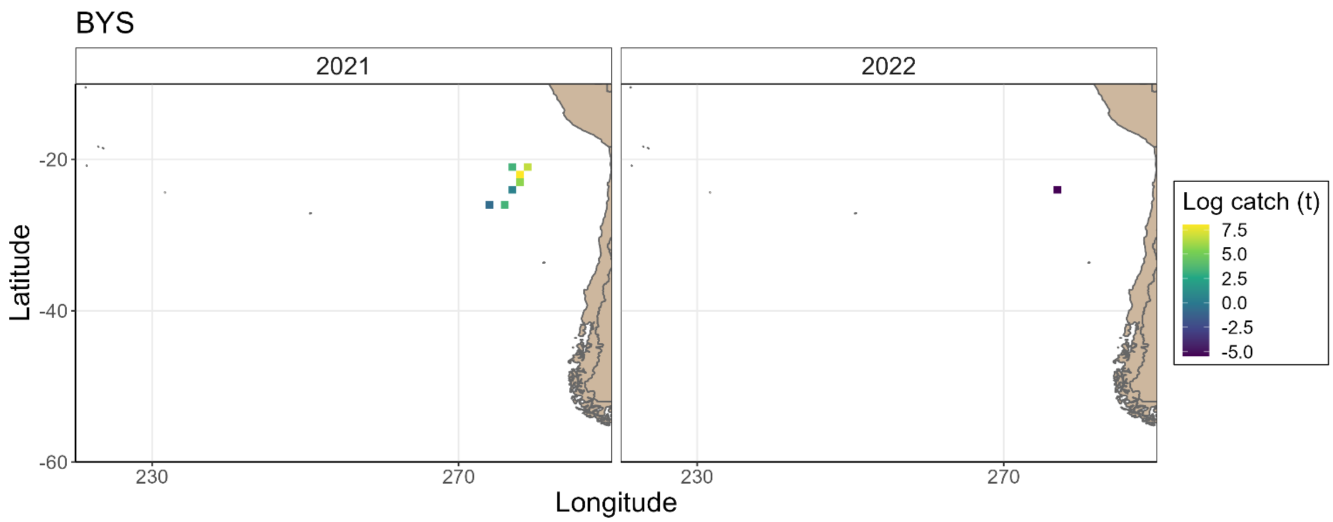
Figures SF1: Spatial distribution of jack mackerel (CJM) catch, by year, as reported in the fishing activity data.



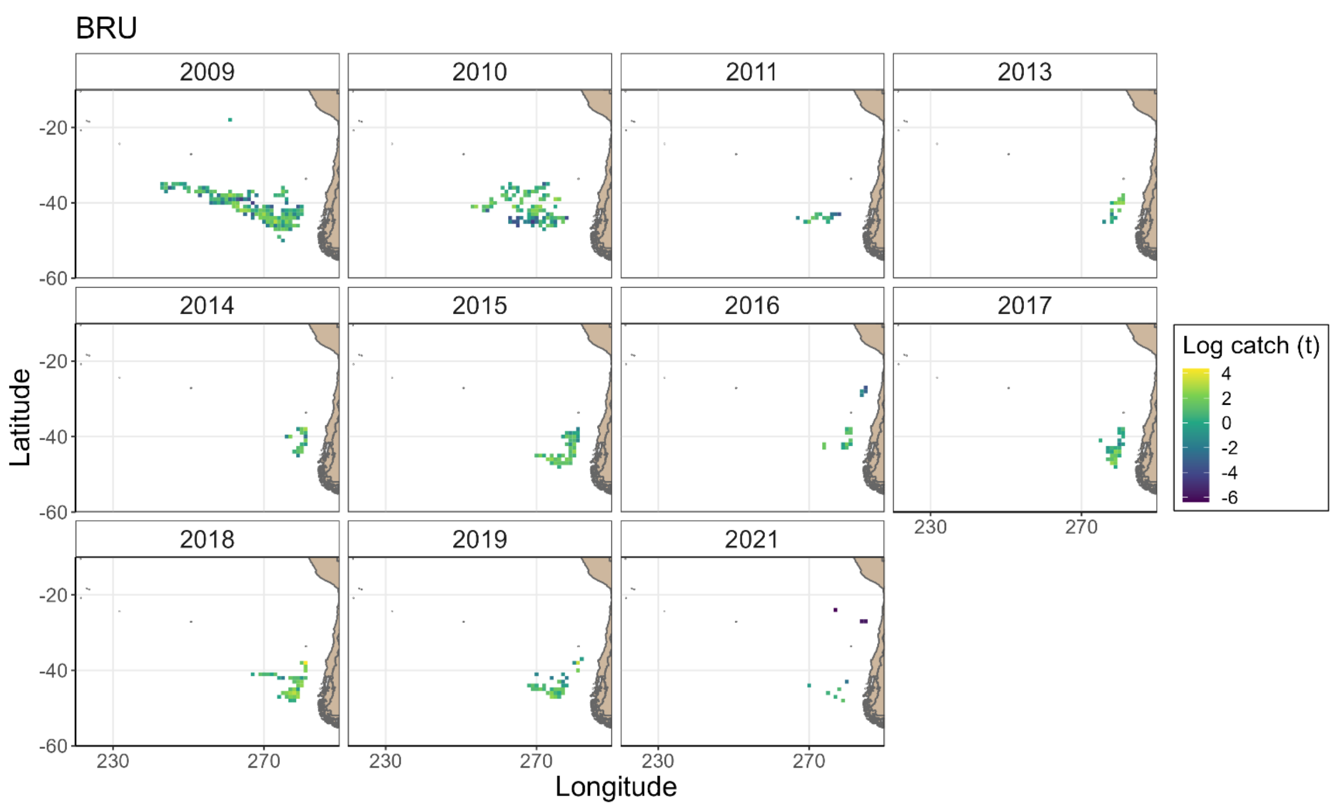
Figures SF2: Spatial distribution of chub mackerel (MAS) catch, by year, as reported in the fishing activity data.



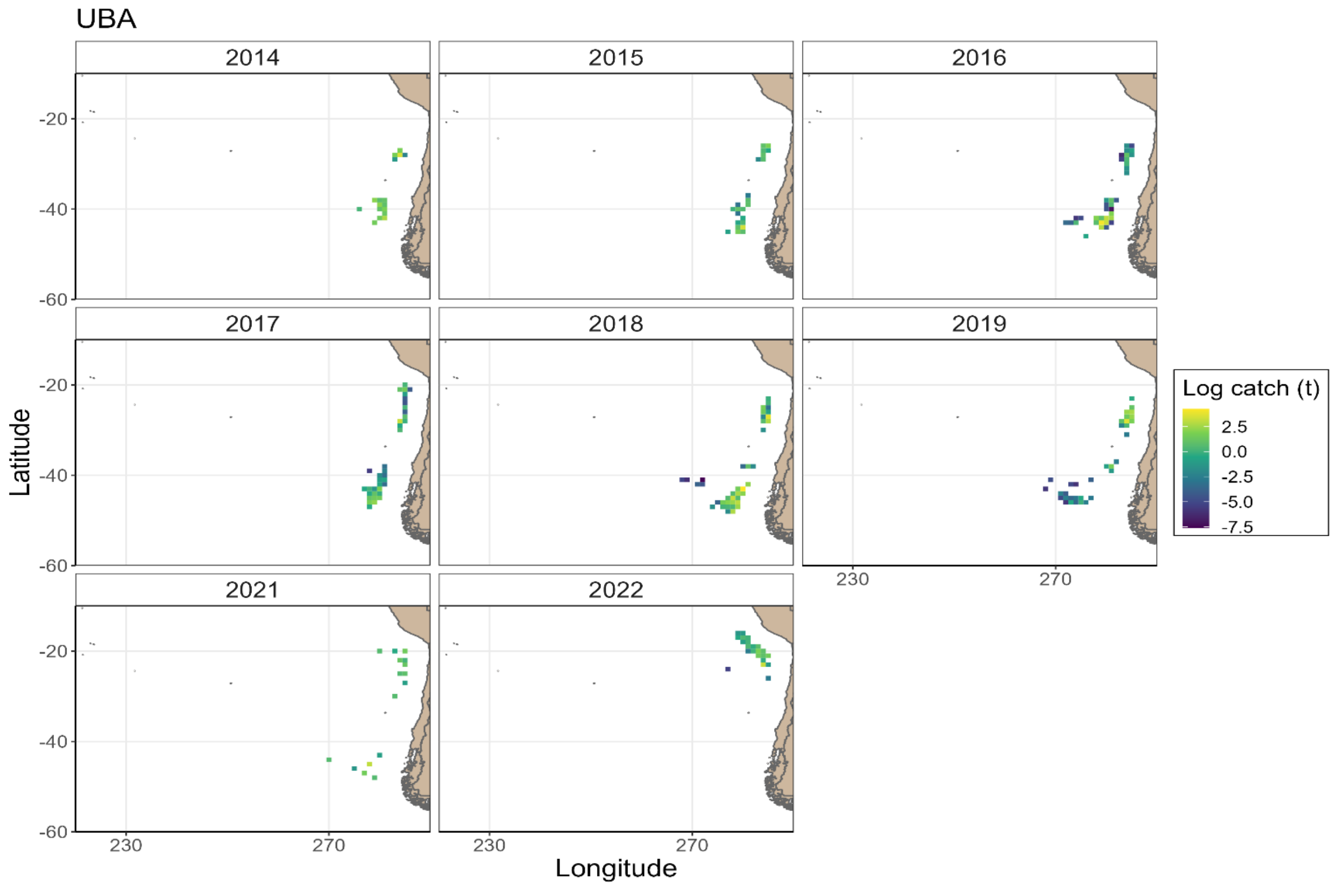
Figures SF3: Spatial distribution of redbait (EMM) catch, by year, as reported in the fishing activity data.



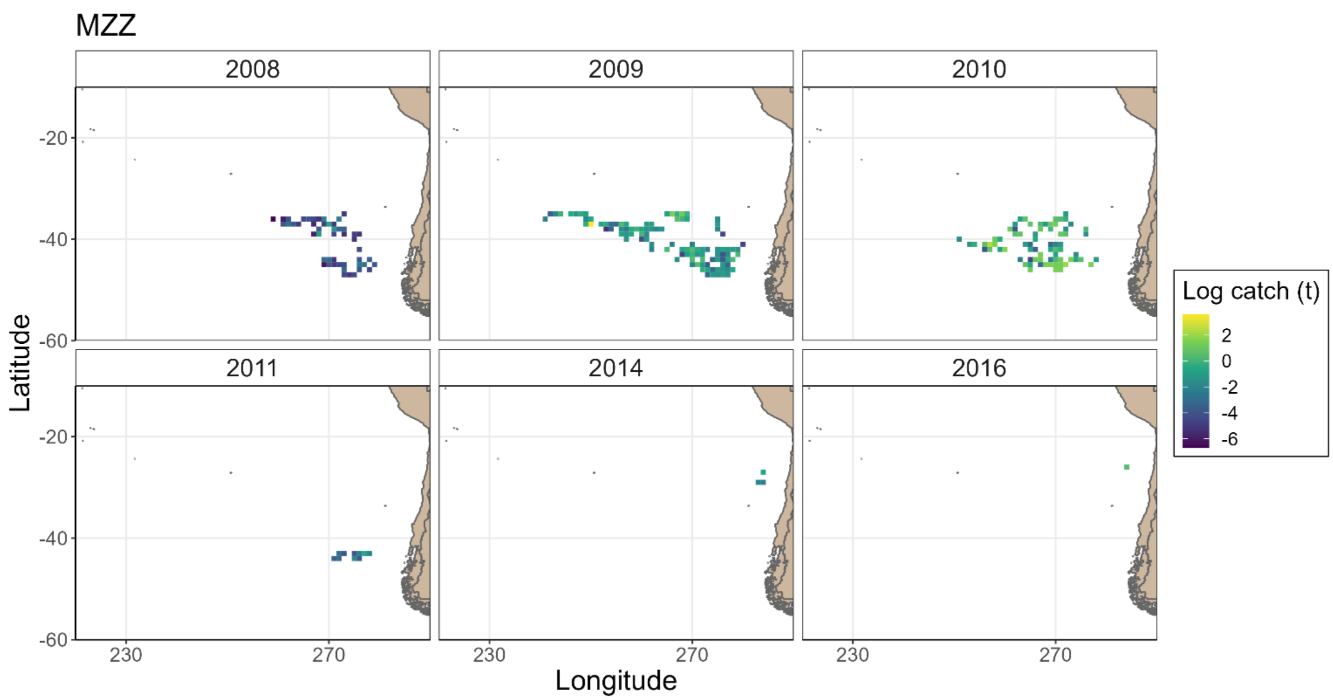
Figures SF4: Spatial distribution of alfonsino (BYS) catch, by year, as reported in the fishing activity data.



Figures SF5: Spatial distribution of southern rays bream (BRU) catch, by year, as reported in the fishing activity data.



Figures SF6: Spatial distribution of blue fathead (UBA) catch, by year, as reported in the fishing activity data.



Figures SF7: Spatial distribution of unclassified marine fishes (MZZ) catch, by year, as reported in the fishing activity data.

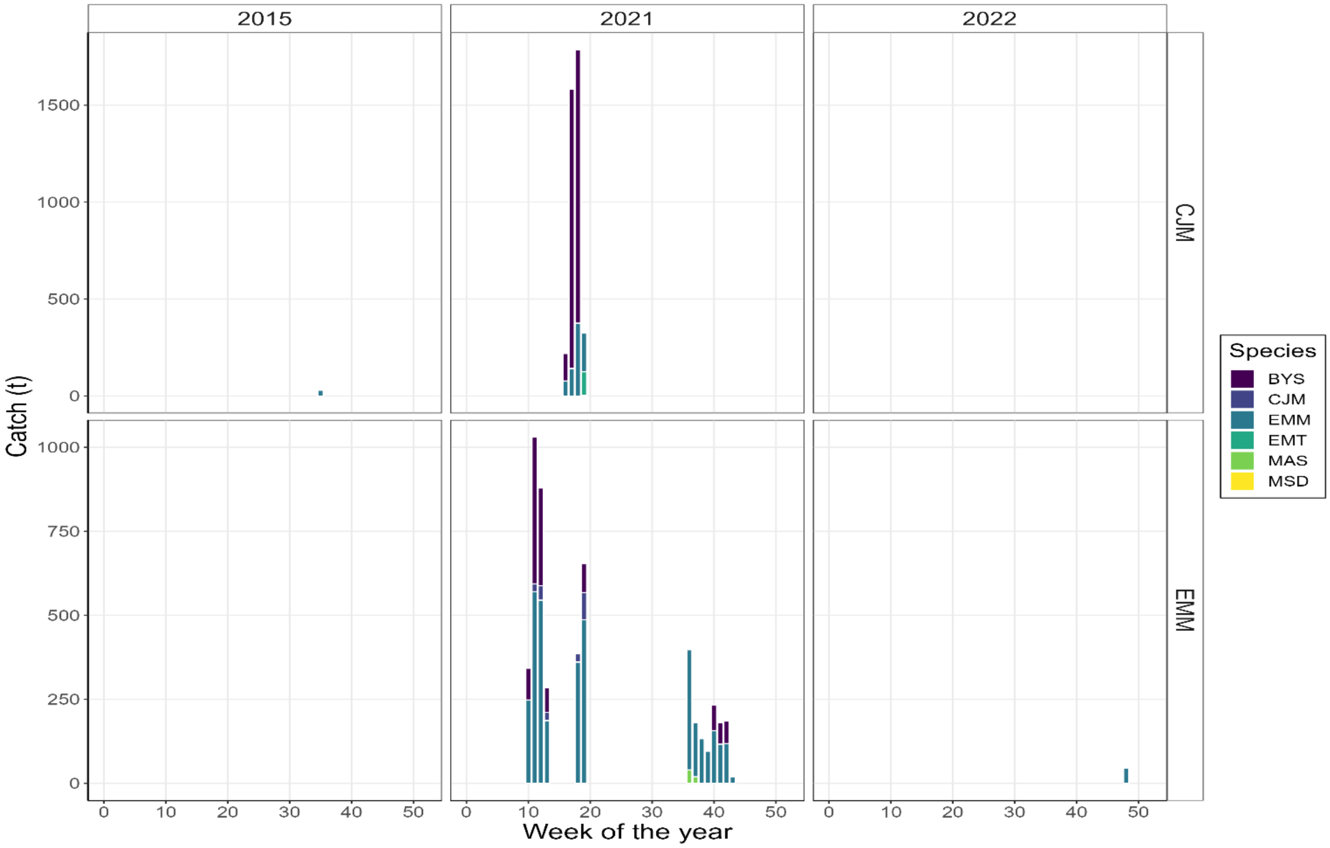


Figure SF8. Catch, by species, year, week, and target species (indicated by rows), for fishing events that caught alfonsino or redbait.

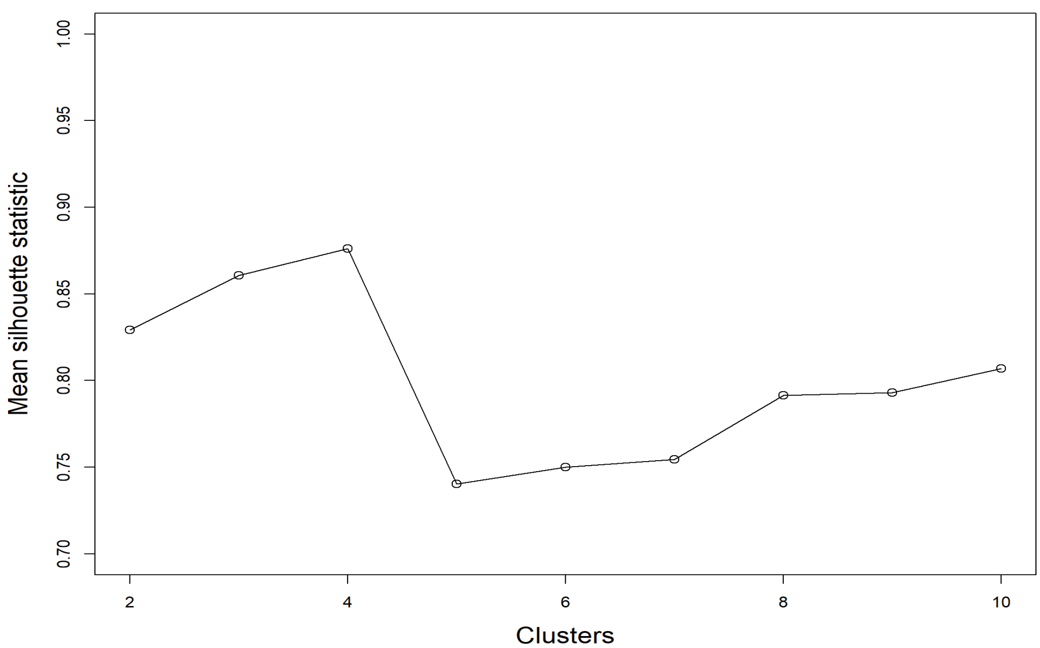


Figure SF9: Mean silhouette statistic as a function of the number of groups the data were clustered into.