8th MEETING OF THE SCIENTIFIC COMMITTEE

New Zealand, 3 to 8 October 2020

SC8-HM06

Habitat monitoring Jack mackerel and chub mackerel 2019-2020 Peru

Peru

NATIONAL FISHERIES SOCIETY - SCIENTIFIC INVESTIGATION COMMITTEE
HUMBOLDT INSTITUTE OF MARINE AND AQUACULTURE RESEARCH

Eighth Workshop on the habitat of Jack mackerel and other species of the Peruvian Current in the Humboldt System organized by SNP in cooperation with IHMA and participation of IMARPE. Lima, July 6th to 10th, 2020

South Pacific Regional Fisheries Management Organization
8th Meeting of the Scientific Committee
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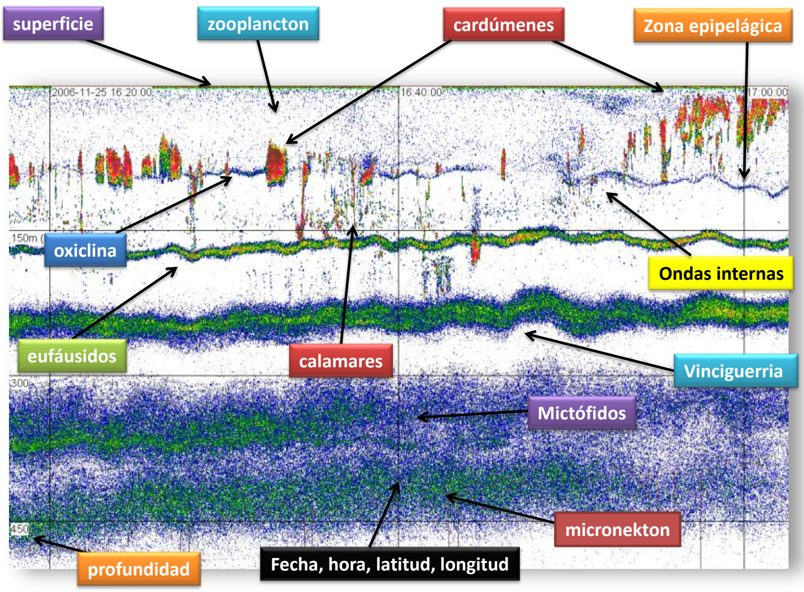
Habitat modeling of Jack mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*) in the Peruvian jurisdictional waters between 2019 and 2020



Daniel Grados, Carlos Valdez, Susan Montero, Salvador Peraltilla, Rodolfo Cornejo, Martín Santivañez, Lucero Moreno, Anibal Aliaga, Mariano Gutiérrez

This report contains information on the Jack mackerel fish stock and fishery in Peruvian jurisdictional waters that, we reiterate, the delegation of Peru provides voluntarily and in use of its discretionary powers for the purposes of information and scientific research within the Scientific Committee of the SPRFMO. In doing so, it is also reiterated that Peru has not given the express consent contemplated in Article 20 (4) (a) (iii) of the Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean. Therefore, as established in Article 5 of the Convention, it is reaffirmed that the decisions and conservation and management measures adopted by the SPRFMO Commission are not applicable to the jurisdictional waters of Peru.

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Habitat modeling of Jack mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*) in the Peruvian jurisdictional waters between 2019 and 2020

Daniel Grados (1), Carlos Valdez (1), Susan Montero (2), Salvador Peraltilla (3), Rodolfo Cornejo (1), Martín Santivañez (4), Lucero Moreno (5), Anibal Aliaga (6), Mariano Gutiérrez (2)

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Summary

Habitat modeling allows us to reconstruct and eventually predict the areas where a particular species has optimal conditions for its survival. Once we have a model that reproduces the tolerance or relationships of the species to a certain set of environmental variables, we can then proceed to make a prediction about its geographic distribution. Eventually, a validated model can be used in stock assessment and fishery management.

However, in the cases of Jack mackerel and chub mackerel - and many others - in areas of national jurisdiction of Peru, the high environmental variability produces different conditions in each season over extended periods of time. This is so because the observation covered period has not been long enough in terms of time and/or geographical scale to expect that a habitat model is really efficient.

In the case of Jack mackerel and chub mackerel, in this document, the pretense of modeling is obviously restricted to the stock or subpopulation of these species in the waters under national jurisdiction of Peru, it cannot be given the same use throughout the wide range of distribution of these species. Furthermore, given the focus on the areas of operation of the Peruvian industrial fleet in the Peruvian jurisdictional waters, the analyses and results in this paper mostly refer to the northern part of the Peruvian Current, within Peruvian jurisdictional waters.

In the present case, a GAM modeling for Jack mackerel and chub mackerel is described, pending a review of all the years (since 2011) in which the National Fisheries Society ("SNP" for its acronym in Spanish) has been systematically collecting information to carry out diagnoses on the status of these populations. Likewise, it is necessary to include in this proposed review the wealth of information collected by Peruvian Marine Research Institute ("IMARPE" for its acronym in Spanish) since the beginning of the fishery.

For the used Generalized Additive Models (GAM), the Response Variable proposed was the obtained catches. The candidate covariates were: chlorophyll concentration (as an indicator of the presence of euphasiids), latitude, longitude, time of day, month, year, sea surface temperature (SST), anomaly of SST (ATSM), surface level anomaly (SLA), and altimetry of sea surface (ASM). Before the modeling exercise, an exploratory data analysis was performed to reveal possible aggregations or relationships between environmental variables.

1. Introduction

Habitat modeling allows us to reconstruct and eventually predict the areas where a particular species has optimal conditions for its survival. The modeling uses two types of data: georeferenced information on the presence of individuals (latitude and longitude) and environmental data at the observation sites (salinity, temperature, chlorophyll, etc.). This information is taken to another space without spatial coordinates, but with environmental coordinates to delimit an "ecological space", where the previously known characteristics of the ideal habitat are those that determine the suitability of the ecological niche thus constructed. Once we have a model that reproduces the tolerance or relationships of the species to a certain set of environmental variables, then it is possible to make a prediction over the geographic space. Eventually, a validated model can be used in fish stock assessment and fishery management.

However, in the cases of Jack mackerel and chub mackerel - and many others - of the Peruvian Current, the high environmental variability produces different conditions in each season over extended periods of time. Thus, multivariate statistical correlations may seem robust at the time they were obtained, but when testing consistency with those of other years there is a low correlation between them. This is so because the covered observation period has not been extensive enough in terms of time and geographical scale to expect that a habitat model is really efficient. It is therefore worth noting that for the time being the analyses and results in this paper mostly refer to the northern part of the Peruvian Current, within Peruvian jurisdictional waters.

Another problem and limitation is that our data is restricted to a certain season, mostly summer. This means that we have data only for a certain part of the interannual and seasonal variability and, as a result, we would not have information on the entire area and time interval of interest that allows us to define the habitat. For modeling, it is necessary to be certain that the environmental variables to be explored are adequately represented in the entire range of environmental conditions. In the case of Jack mackerel and chub mackerel, regarding this document, the pretense of modeling is obviously restricted to the stock or subpopulation of these species inhabiting in the northern part of Peruvian Current. In other words, our results cannot be given the same use throughout the wide range of distribution of these species.

In the present case, a GAM modeling has been carried out for Jack mackerel and chub mackerel, pending a review of all the years (since 2011) in which the SNP has been systematically collecting information to perform diagnoses on the status of these populations.

2. Modeling the distribution of Jack mackerel and chub mackerel

As indicated, it is challenging to identify and model the factors that potentially influence or determine the Jack or chub mackerel habitats. In the present case, the candidate factors for the exercise of modelling the habitat of both species have been identified. However, the used data comprised years 2019 to 2020 only.

The proposed Response Variable was capture (in tons). The candidate covariates were: chlorophyll concentration (as an indicator of the presence of euphasiids), latitude, longitude, time of day, month, year, sea surface temperature (SST), anomaly of SST (ATSM), surface level anomaly (SLA), and altimetry of sea surface (ASM).

Before the modeling exercise, an exploratory data analysis was performed to reveal possible aggregations or relationships between environmental variables. A Principal Component analysis (PCA) was carried out to explore the relationship between environmental variables. The first three main components were selected, which explain 82% of the variability of the relationships between the parameters. For the relationship analysis, a bi-plot figure has been constructed (figure 2.1) in which differences in catches can be seen according to environmental parameters and proximity to the coast. That figure 2.1 is referred to Jack mackerel only.

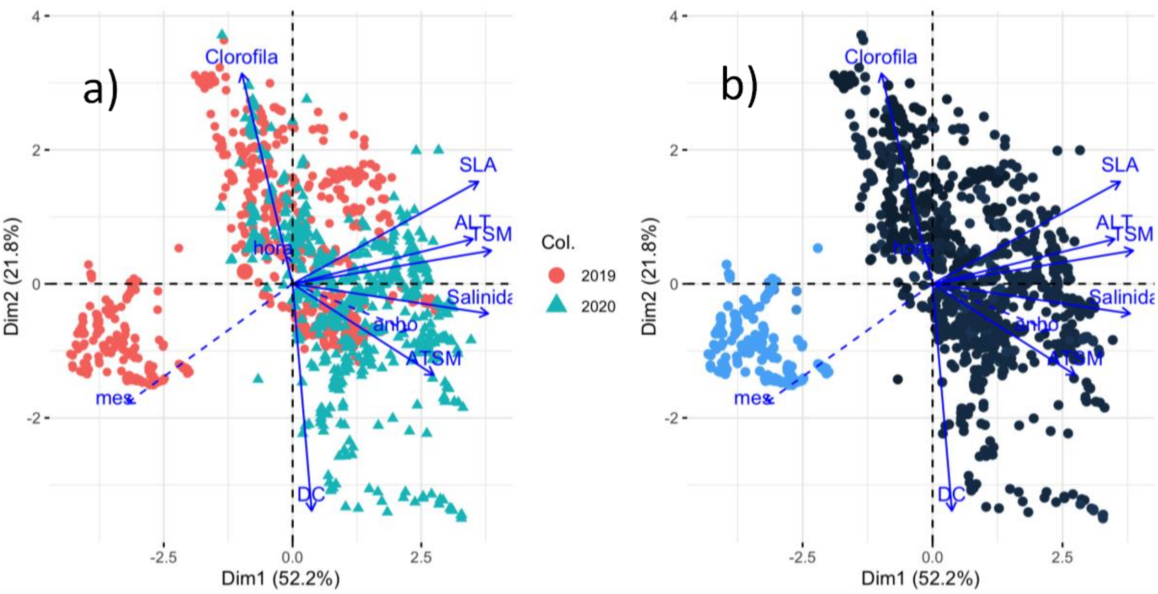

Figure 2.1. PCA analysis of the environmental characteristics associated with Jack mackerel fishing operations during 2019 and 2020. a) Separation by year of fishing operations; and b) separation by months of fishing operations (Clorofila=Chlorophyll; SLA= sea level anomaly, ALT=altimetry; TSM=sea surface temperature,

Salinidad= salinity, anho=year, ATSM=anomalies of sea surface temperature., DC=distance from the coast, mes=month).

On the left side of figure 2.1, it can be seen that the catches obtained during the first half of 2019 were made in areas with a high concentration of chlorophyll and closer to the coast, unlike the first half of 2020, which were catches made in areas with a lower concentration of chlorophyll and further from the coast.

Another result come from the separation of the environmental characteristics for the second semester of the year 2019 (right side of the figure 2.1), where the captures were made under environmental conditions with relatively low surface temperature values, and with low salinity values.

Based on what was observed in the PCA, a grouping analysis was carried out, in order to describe the observed environmental characteristics. Thus, 3 clusters were identified (figure 2.2.).

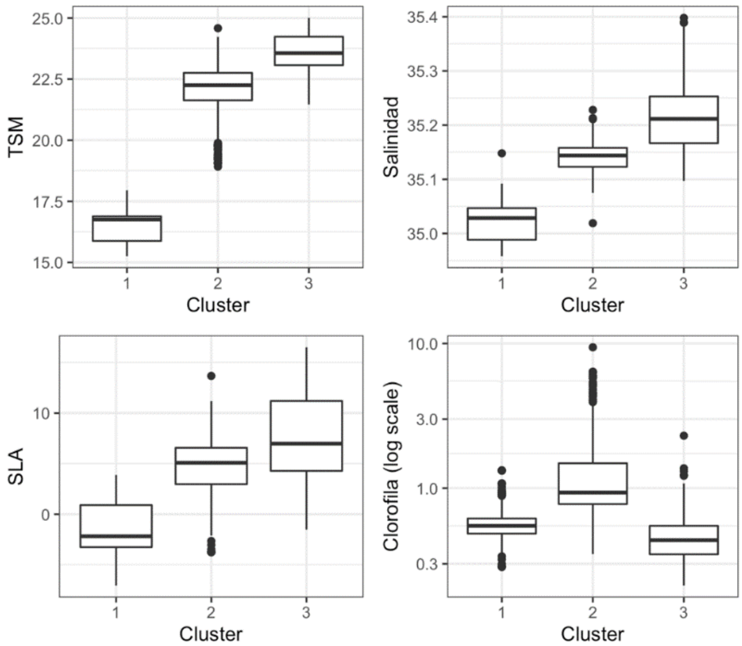

Figure 2.2. Results of the grouping analysis, 3 groups were observed which are shown according to the environmental characteristics (TSM: sea surface temperature; salinidad: sea surface salinity; SLA: surface level anomaly; clorofila: chlorophyll (in logarithm scale)).

In figure 2.2. it can be seen that for cluster 1, the sea surface temperature values were lower (~16°C) and with the lowest salinity values; furthermore, the abnormality values are negative and chlorophyll concentrations are also low. It is worth mentioning that this cluster corresponds to the environmental conditions of the second semester of 2019.

For cluster 2, it is observed that sea surface temperature (SST) values are around 22°C, with intermediate salinity values, and with surface level anomaly (SLA) values of around 5 cm. Likewise, this type 2 cluster presents the highest chlorophyll concentration values, and correspond to the summer 2019. Finally, cluster 3 presents the highest SST values, with high salinity values, like SLA, and the lowest chlorophyll values; this third cluster corresponds with summer 2020.

These analyzes showed that there are seasonal differences. That is why it was decided to carry out a modeling for different seasons of the year.

2.1. Seasonal modeling of Jack mackerel catches

2.1.1. First semester of 2019

The relationships between Jack mackerel catches and the factors that define their habitat were quantified using generalized additive models (GAM). The response variable was the logarithmically transformed catch with potential covariates, including the environmental and spatial-temporal variables listed before as candidate covariates. For the GAM model, the identity binding function was used.

For the data of the first half of 2019, 4 models were considered. Among them it was chosen the model that had the best predictive capacity. Based on the comparison analyzes, model 3 was chosen (not all models that were developed are presented in this document). Model 3 has the peculiarity of incorporating the hold capacity and spatial autocorrelation. The model explains 23% of the variability of the Jack mackerel catch.

In Table 2.1.1. they are observed each parameter considered including their significance. It can be seen that chlorophyll (Clorofila) and altimetry (ALT) are not significant parameters to explain the variability of the Jack mackerel catch.

Table 2.1.1. GAM model for the first semester of 2019, used to explore the variables that best represent the catches obtained for Jack mackerel (TSM=sea surface temperature, salinidad=salinity, clorofila=chlorophyll, ATSM=sea surface temperature anomaly, SLA:surface level anomaly, ALT=altimetry, DC=distance from the coast, CAP_BOD_M3=hold capacity in cubic meters, hora=time, longitude=longitude, latitude=latitude).

Variables	edf	Residual	F	p-value	
s(TSM)	5.360	6.533	2.183	0.04	*
s(Salinidad)	2.699	3.446	3.489	0.01	*
s(Clorofila)	1.000	1.000	1.676	0.2	
s(ATSM)	2.99	3.746	3.030	0.02	*
s(SLA)	4.942	6.069	2.670	0.01	*
s(ALT)	1.738	2.185	0.362	0.62	
s(DC)	6.238	7.401	2.995	<0.01	**
s(CAP_BOD_M3)	1.924	2.409	5.354	<0.01	**
s(hora)	1	1.000	11.01	<0.01	***
te(LONGITUD, LATITUD)	14.043	15.075	2.627	<0.01	***

Figure 2.1.1. presents the graphical result of the GAM modeling for Jack mackerel. Values of around 23°C are better correlated with the catches of Jack mackerel. Furthermore, for salinity the better correlated values are between 35.1 and 35.2. The temperature anomaly includes values over zero (fishing operations with positive anomalies). Furthermore, with regard to altimetry and altimetry anomaly, it is observed that the fishing operations were carried out in areas with positive anomalies. The values corresponding to distance to the coast (DC) show results that as the DC increases, the catches decrease.

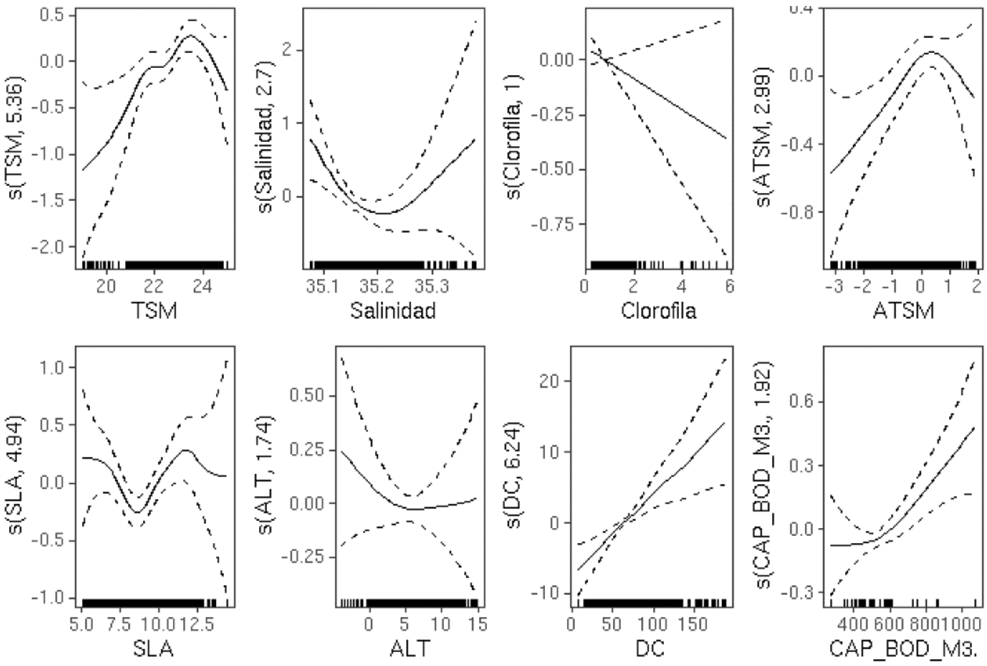

Figure 2.1.1. GAM modeling of Jack mackerel catches for the first semester of 2019. (TSM=sea surface temperature, salinidad=salinity, clorofila=chlorophyll, ATSM=sea surface temperature anomaly, SLA:surface level anomaly, ALT=altimetry, DC=distance from the coast, CAP_BOD_M3=hold capacity in cubic meters, hora=time, longitude=longitude, latitude=latitude).

2.1.2. Second semester of 2019

As for the first semester of 2019, the relationships between Jack mackerel catches and the factors that define their habitat were quantified using GAM models for the second semester of 2019. The response variable was the logarithm of the catch, and several environmental and spatial-temporal variables were included as potential covariates. For the GAM model, the identity binding function was used. Four GAM models were considered; among them, the model that had the best predictive capacity was chosen. Based on the comparison analyzes, model 3 was chosen which also used as parameter the hold capacity of every vessel. The chosen model explains 27% of the variability of the Jack mackerel catch. Table 2.1.2. presents the GAM results of each parameter, including their significance. Unlike the first semester, only the altimetry anomaly (SLA) and spatial autocorrelation are significant to explain the variability of catches.

Table 2.1.2. GAM model for the second half of 2019, made to explore the variables that best represent the catches obtained for Jack mackerel. (TSM=sea surface temperature, salinidad=salinity, clorofila=chlorophyll, ATSM=sea surface temperature anomaly, SLA:surface level anomaly, ALT=altimetry, DC=distance from the coast, CAP_BOD_M3=hold capacity in cubic meters, hora=time, longitude=longitude, latitude=latitude).

Variables	edf	Residual	F	p-value	
s(TSM)	1.29	1.52	1.59	0.29	
s(Salinidad)	0.99	0.99	2.84	0.09	
s(Clorofila)	1.00	1.00	0.27	0.60	
s(ATSM)	1.00	1.00	0.65	0.42	
s(SLA)	7.31	8.23	4.03	<0.01	***
s(ALT)	1.00	1.00	0.77	0.38	
s(DC)	0.99	0.99	0.27	0.60	
s(CAP_BOD_M3)	1.74	2.08	1.84	0.15	
te(LONGITUD, LATITUD)	6.21	6.80	4.13	<0.01	***

Figure 2.1.2. presents the graphic GAM results for Jack mackerel catches for the second semester of 2019. Only the altimetry anomaly was significant to explain the variability of catches.

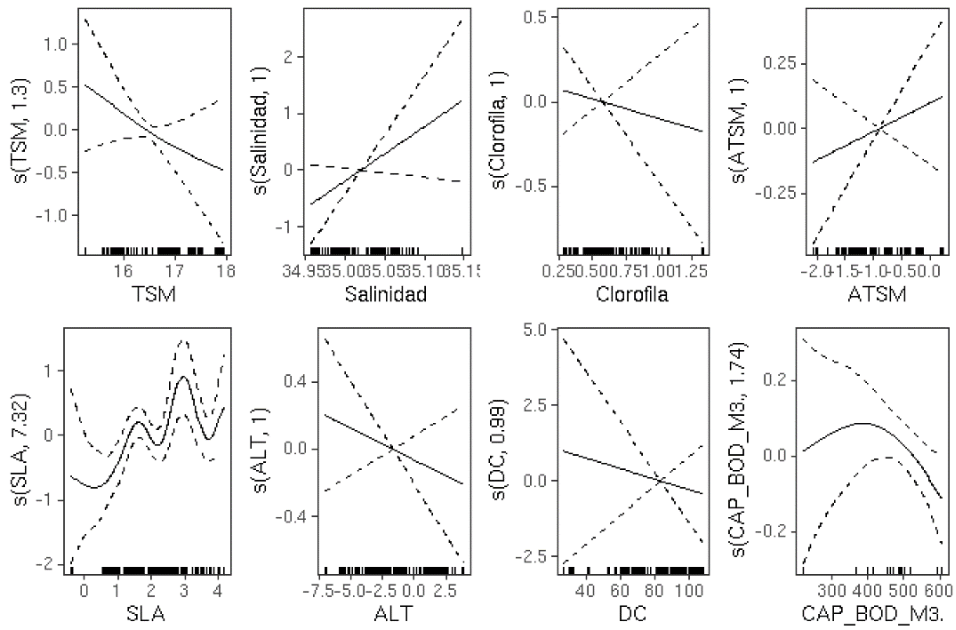

Figure 2.1.2. List of parameters used for GAM modeling of Jack mackerel catches. Model for the second half of 2019. (TSM=sea surface temperature, salinidad=salinity, clorofila=chlorophyll, ATSM=sea surface temperature anomaly, SLA:surface level anomaly, ALT=altimetry, DC=distance from the coast, CAP_BOD_M3=hold capacity in cubic meters, hora=time, longitude=longitude, latitude=latitude).

2.2. Seasonal modeling of chub mackerel catches

2.2.1. First semester of 2019

The relationships between chub mackerel catches and some of the factors that define their habitat were quantified using GAM. The response variable was the logarithmically transformed catch with potential covariates, including environmental and spatial-temporal variables. For the GAM model, the identity binding function was used.

Three models were developed for the first half of 2019. Among them, the model with the best predictive capacity was chosen. Based on the comparison analyzes, model 3 was chosen (the results of all models are not presented in this document). This model 3 has the peculiarity of incorporating the hold capacity of every vessel as a variable, as well as the spatial autocorrelation. The model explains 40% of the variability of the chub mackerel catch.

In Table 2.2.1. The results of each considered parameter are presented. It is included the significance of each parameter. According to the results of the model, chlorophyll, altimetry anomaly (SLA), the distance to the coast (DC), the hold capacity and the spatial autocorrelation are significant to explain the variability of the chub mackerel catches.

Table 2.2.1. GAM model for the first semester of the year used to explore the variables that best represent the catches obtained from chub mackerel (TSM=sea surface temperature, salinidad=salinity, clorofila=chlorophyll, ATSM=sea surface temperature anomaly, SLA:surface level anomaly, ALT=altimetry, DC=distance from the coast, CAP_BOD_M3=hold capacity in cubic meters, hora=time, longitude=longitude, latitude=latitude).

Variables	edf	Residual	F	p-value	
s(TSM)	3.39	4.27	0.74	0.54	
s(Salinidad)	1.00	1.00	1.50	0.22	
s(Clorofila)	6.34	7.43	3.07	0.00	**
s(ATSM)	1.97	2.51	1.28	0.34	
s(SLA)	5.92	7.06	2.07	0.05	*
s(ALT)	1.30	1.54	1.23	0.21	
s(DC)	1.00	1.00	5.18	0.02	*
s(CAP_BOD_M3.)	8.46	8.91	2.86	0.00	**
s(hora)	1.64	2.05	0.81	0.46	
te(LONGITUD,LATITUD)	6.13	7.27	2.25	0.02	*

Figure 2.2.1. presents the graphical result of the GAM modeling for chub mackerel. Values around 22°C to 24°C are observed with the highest relationship with chub mackerel catches. Furthermore, for salinity the values are placed in a very limited range (between 35.1 and 35.2). The temperature anomaly comprises values around zero. Furthermore, with respect to altimetry and altimetry anomaly (SLA), it is observed that the fishing operations were carried out in zones with positive anomalies.

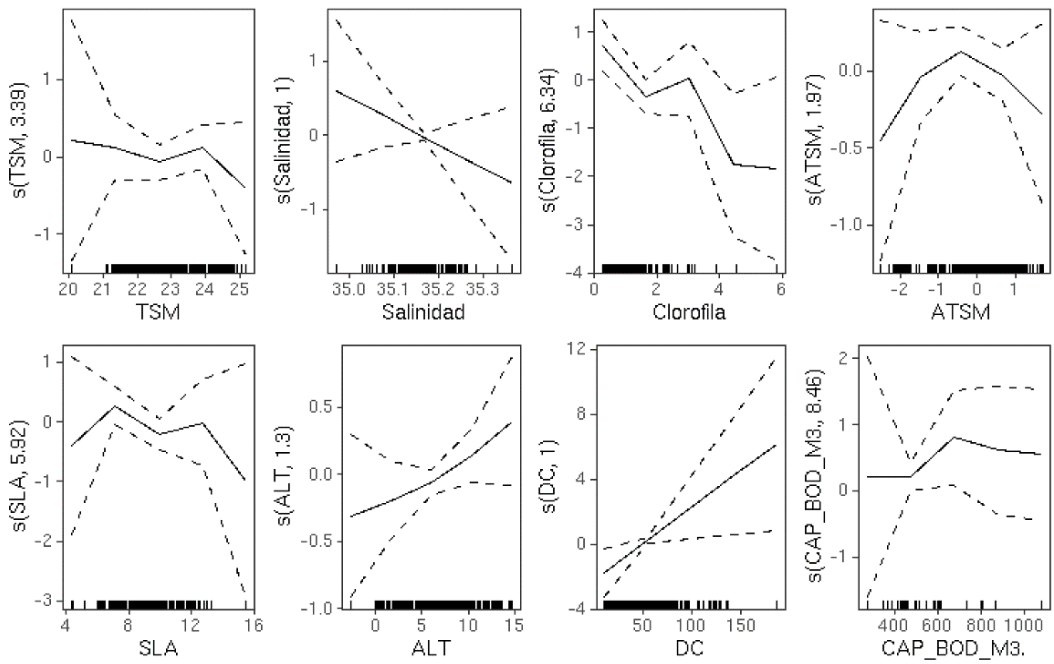

Figure 2.2.1. List of parameters used for the GAM modeling of chub mackerel catches for the first half of 2019. (TSM=sea surface temperature, salinidad=salinity, clorofila=chlorophyll, ATSM=sea surface temperature anomaly, SLA:surface level anomaly, ALT=altimetry, DC=distance from the coast, CAP_BOD_M3=hold capacity in cubic meters, hora=time, longitude=longitude, latitude=latitude).

Modeling was not performed for the second semester of 2019 because only a few fishing operations were recorded.

3. Mass and vertical distribution indices for Jack mackerel

An Aggregation Index (AI) and a vertical Center of Mass (CM) were calculated.

$$IA = \frac{\int S_v(z)^2 dz}{\left(\int S_v(z) dz\right)^2}, m^{-1}$$

$$CM = \frac{\int z S_v(z) dz}{\int S_v(z) dz}, CM$$

Where z is the depth of the sampling layer (m); and Sv is the coefficient of the acoustic backscatter volume strength (dB/m).

For this, the Peruvian jurisdictional waters were grilled by Marsden 60 x 60-minute squares. Within each polygon thus generated, AI and CM were calculated using the information from all acoustic detections (Jack mackerel fish schools). The AI index is higher when the highest fish densities are distributed in small areas (Urmy et al.[1], 2012), while the CM indicates the central position of Jack mackerel in the water column (Figure 3.1).

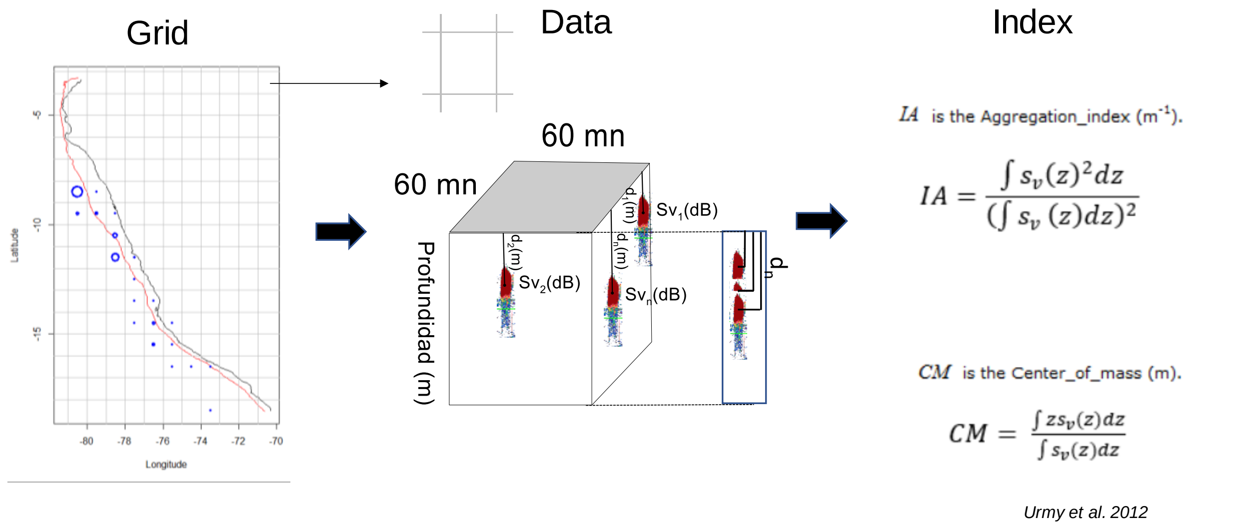

Figure 3.1. Calculation process of indices of aggregation (IA) and vertical distribution for Jack mackerel (CM)

The analyzes of the IA and CM were divided by semesters of the year, this means that 3 calculations were made: for the first and second semester of 2019, and first semester of 2020.

The results for the IA are presented in Figure 3.2. It can be seen that by the summer of 2020, Jack mackerel was found to be more aggregated in the water column while during summer of 2019 it was found more dispersed. These results are consistent with the CM index (Center of Mass) (Fig. 3.3) where it is observed that during summer 2020 (first semester) the fish was distributed closer to the surface, while during summer 2019 the fish was distributed in deeper areas.

[1]Urmy S., J. Horne, D. Barbee. (2012). Measuring the vertical distributional variability of pelagic fauna in Monterey Bay. ICES Journal of Marine Science (2012), 69 (2), 184–196. doi: 10.1093 / icesjms / fsr205

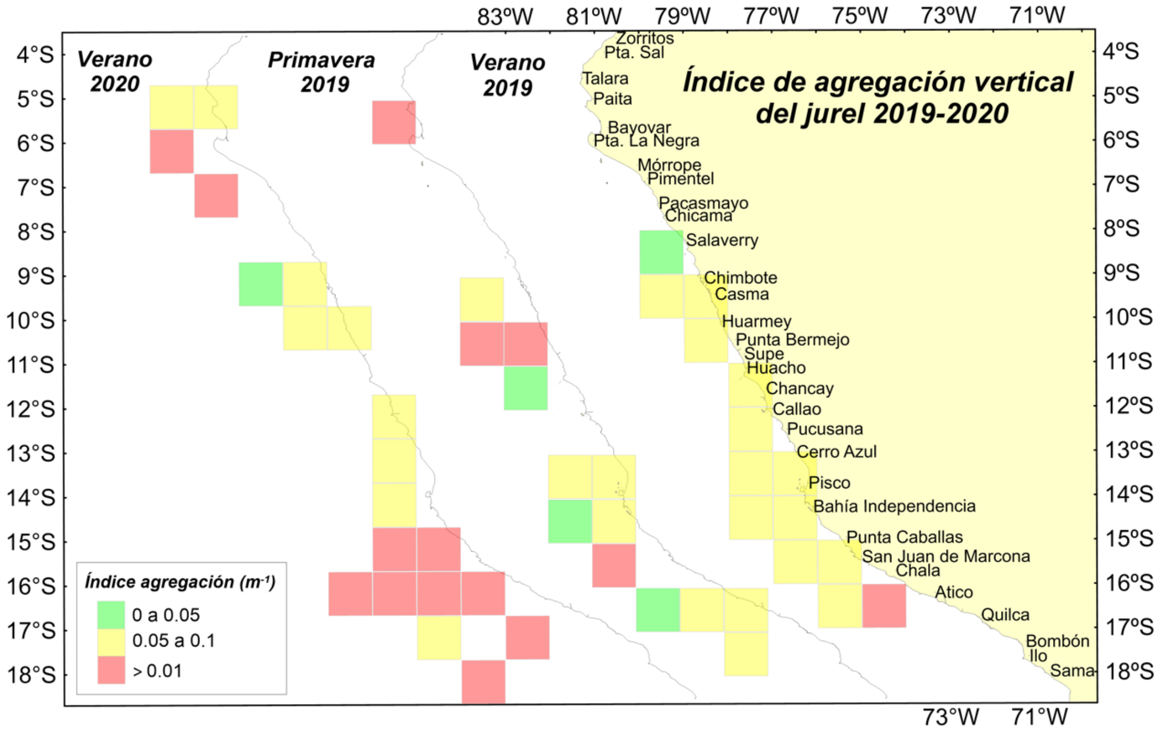

Figure 3.2. Aggregation Index (AI) results for the last 3 periods (summer 2020, spring 2019, summer 2019). These indices were calculated for Jack mackerel only.

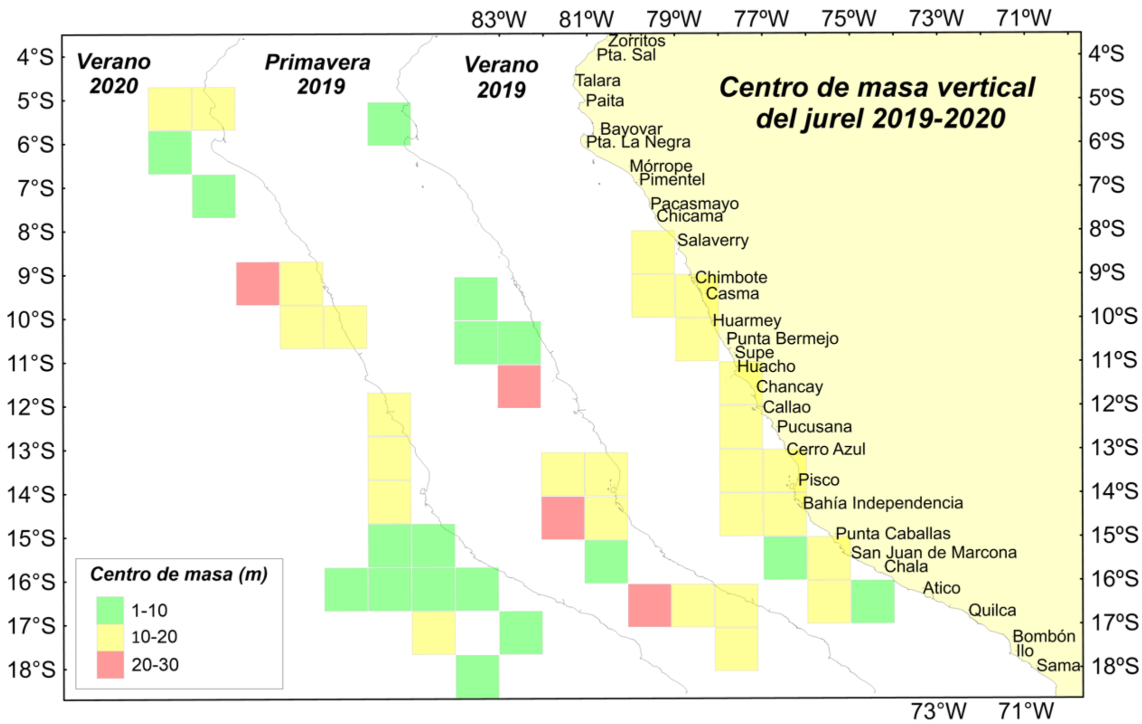

Figure 3.3. Results of Center of Mass (CM) for the last 3 periods (summer 2020, spring 2019, summer 2019). These indices were calculated for Jack mackerel only.

4. Potential Jack mackerel habitat model (MHPJ)

Valdez et. to (2015[2]) developed a 2D deterministic and probabilistic model (MHPJ) to describe the potential habitat of Jack mackerel (*Trachurus murphyi*) using information from satellite oceanography and position variables (six parameters in total). The catches of Jack mackerel were better correlated to the model when it reached values greater than 0.6 (within a range from 0 to 1).

However, the model is strongly influenced by low values of chlorophyll, so that quality of the results depends on the availability of clear satellite images (that is, not covered by clouds). The MHPJ was run biweekly for the months of January to March (two runs per month), and for the years 2018 to 2020. In order to make a monthly comparison, the mean MPHJ was calculated for each month.

The results are shown in Figure 4.1. The catches obtained by the fishing fleet were plotted to visualize the assertiveness of the model. To make a spatial-temporal analysis, the gravity center (CG (x: y)) of values by each model run was calculated for probability values higher than 0.75. Also, the distance to the coast (DC) of every fishing set was calculated to analyze the relationship of the latitude versus DC.

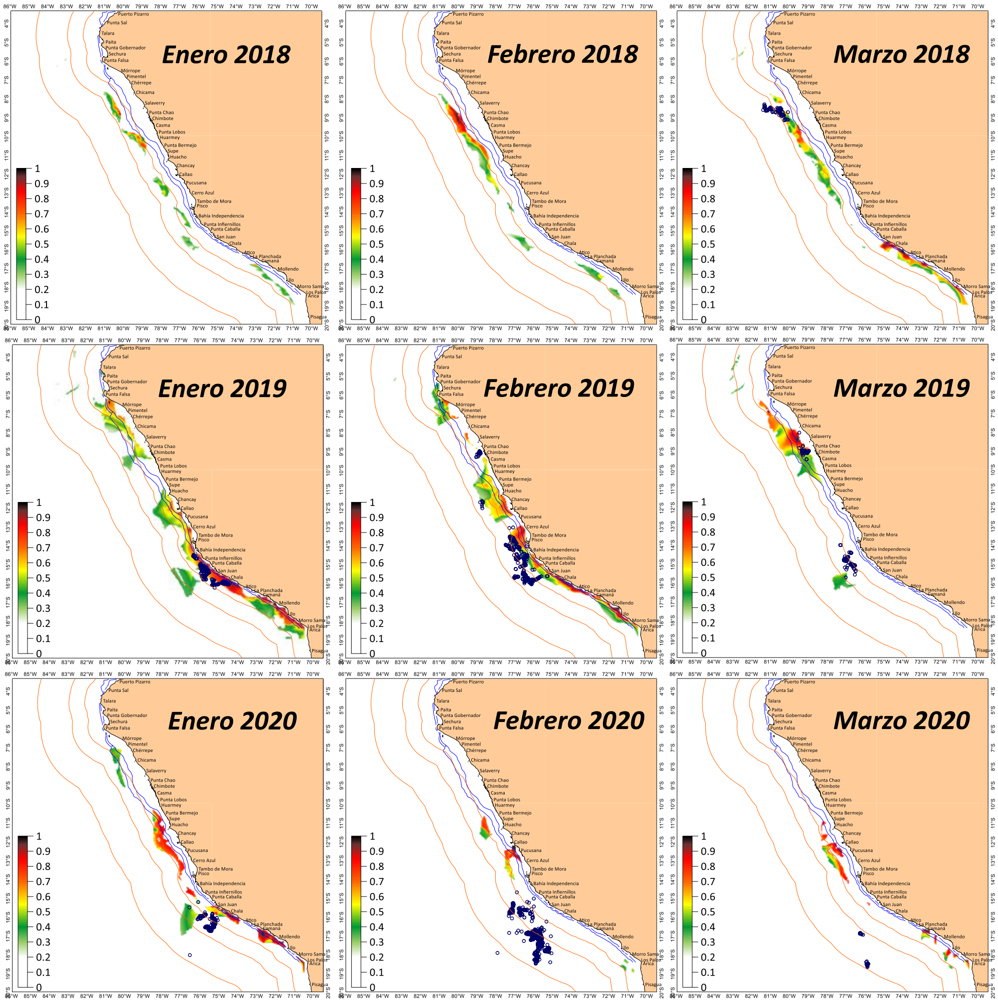

Figure 4.1. Result of the MHPJ between January and March from 2018 to 2020. The black dots indicate the catches (fishing sets) made by the fleet. The distance to the coast is represented by the orange lines (50, 100

[2]Valdez C., S. Peraltilla, M. Gutiérrez, E. Méndez, A. Aliaga, A. Zuzunaga, D. López, U. Munaylla & F. Gerlotto. (2015). Modeling Jack mackerel (Trachurus murphyi) potential habitat of Peru validated throughout industry vessels catch and acoustic data. Proceedings of the RIO Acoustics 2015 IEEE / OES Acoustics in Underwater Geosciences Symposium, Rio de Janeiro, July 2015.

and 200 nm respectively). The blue lines represent the 80 and 200 m bathymetry isolines. The color scale indicates the probability of finding Jack mackerel (values ranging from 0 to 1).

During 2018, it is observed that the model has the same trend for the three months, with possible positive habitat areas between 50 and 100 nautical miles (nm) in the central zone, while the habitat expands further south during March within the first 50 nm. During March, catches are observed off Chimbote where the potential habitat area also reaches this zone.

During January 2019, the habitat has a larger coverage along the entire coast, as in February. In March, this habitat is limited to the central-north zone, where they are observed high probability values, though also there was an area of low probability in the central-south area.

Finally, in January 2020 the model shown a wide range of distribution along the entire coast within 60 nm from the coast, with high probability values in the central zone, as well as some small nuclei in the southern zone. For the subsequent months the habitat is concentrated in the central zone. The assertiveness of the model during this period was low, so that the model could not represent the fishing areas in the southern zone between 50 and 200 nm (Fig. 4.1).

Figure 4.2 shows the spatial-temporal variation of the center of gravity (CG) of each run of the model by years labeled with its corresponding fortnight number. In 2018 it is observed that CG reached 74 nm from the coast, and between latitudes 8.5 to 17.5 ° S. In this case, the first three fortnights indicated a distribution away from the coast. During the last three fortnights, the CG moved towards the coast within the first 25 nm. During 2019, a change of the CG towards the coast is observed. At the latitudinal level, CG have a wide range change, similar to 2018. In 2020, the CG are observed clustered between 7 and 31 nm off coast, and between latitudes from 12 to 15 ° S.

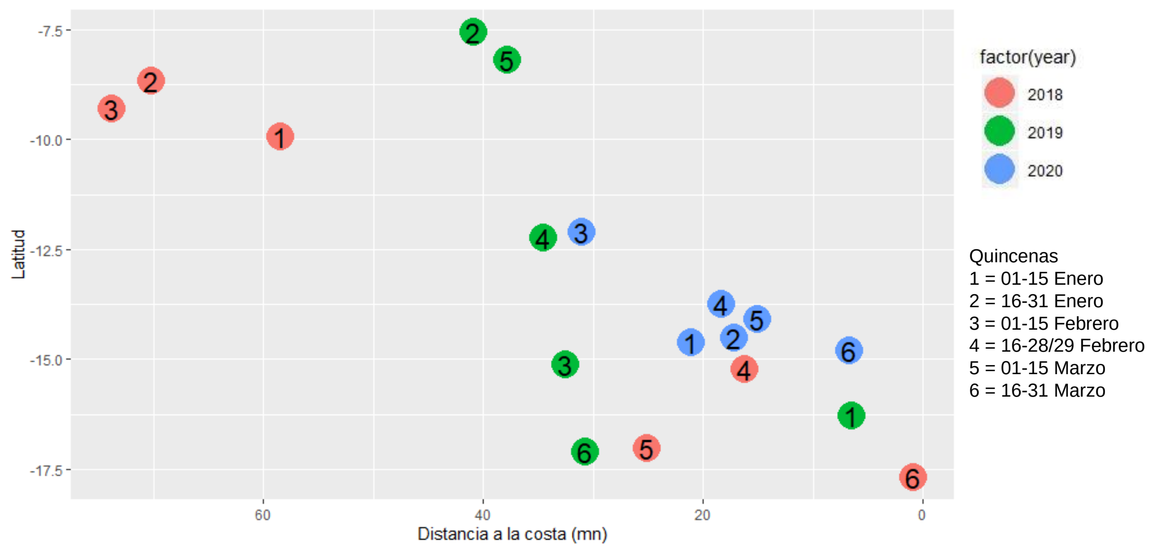

Figure 4.2. Space-time graph of the CGs (Latitude-Distance to the coast (nm)). The colors indicate the years (2018-2020) and the numbers indicate their corresponding fortnight (1 to 6).

Finally, Figure 4.3 shows a comparison between the distribution of Jack mackerel observed during the acoustic survey made by IMARPE during summer 2020 and the distribution estimated with the MHPJ model for March 2020. It must be however made clear that the model is of instantaneous run, while the survey took place along 40 days.

It is then observed that during the survey the Jack mackerel distribution area had few and small nuclei in front of Paita, Casma and Chala, while for the MHPJ there is a strong probability of finding Jack mackerel between Supe and Pisco between 50 and 120 nm, in addition of a strong nucleus in front of Ocoña and Punta Caballas.

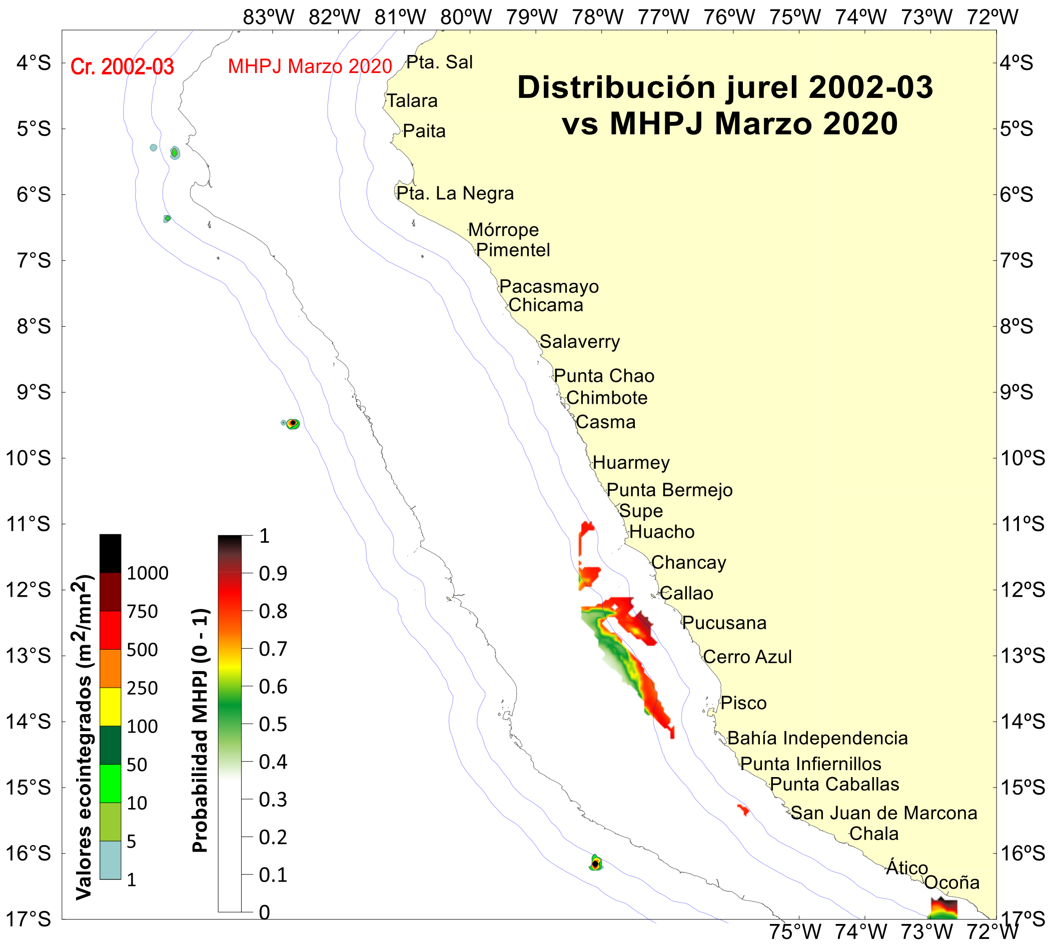

Figure 4.3. Comparison of the MHPJ result with the acoustic detections made during the Acoustic 2002-03 survey during summer 2020. The blue lines indicate distances to the coast at 50 and 100 nautical miles.

5. Conclusions

In the case of Jack mackerel, it is noteworthy that fishing sets made during the first half of 2019 were made in areas with a high concentration of chlorophyll and closer to the coast, unlike the first half of 2020, which were fishing sets made in areas with a lower concentration of chlorophyll and farther from the coast.

Another interesting result in the case of Jack mackerel is that of the environmental characteristics for the second half of 2019, where the fishing sets were made at relatively low surface temperatures, and with low salinity values. Based on what was observed, a grouping analysis was carried out to describe the observed environmental characteristics, thus determining three clusters of Jack mackerel with different conditions.

A GAM modeling of the variables related to the fishing sets made on Jack mackerel. Four different models were considered. The best one of them explains 23% of the variability of the Jack mackerel catches.

By summer of 2020, Jack mackerel was found to be more aggregated in the water column. During summer 2019 Jack mackerel was found more dispersed. These results are consistent with the Center of Mass index, where it is observed that during summer of 2020 Jack mackerel was distributed closer to the surface, while during summer of 2019 it was found in deeper areas.

Regarding the MPDJ model, Jack mackerel catches were better correlated when it reached values greater than 0.6 (within a range from 0 to 1). However, the model is strongly influenced by low values of chlorophyll, so the quality of the results depends on the availability of clear satellite images (that is, not covered by clouds).

In the case of mackerel, 3 GAM models were considered. It was chosen the best of them, which explained 40% of the variability of chub mackerel catches. Chlorophyll, altimetry anomaly, Distance to Coast, hold capacity of every vessel and spatial autocorrelation are significant to explain the variability of chub mackerel catches.

6. Recommendations

A review plan should be developed for as many species and years as possible, using both IMARPE survey data and information collected by the fleet whether environmental information is available to be analyzed as covariates.

Develop a project for the modeling of the habitat of species of interest in cooperation with academic institutions of the region in order to share experiences and cooperate in the development of models that can eventually be used in management.

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