

**8<sup>th</sup> MEETING OF THE SCIENTIFIC COMMITTEE**

*New Zealand, 3 to 8 October 2020*

**SC8-HM05**

**Changes in the habitat of Jack mackerel and Chub mackerel 2018-2020 Peru**

*Peru*

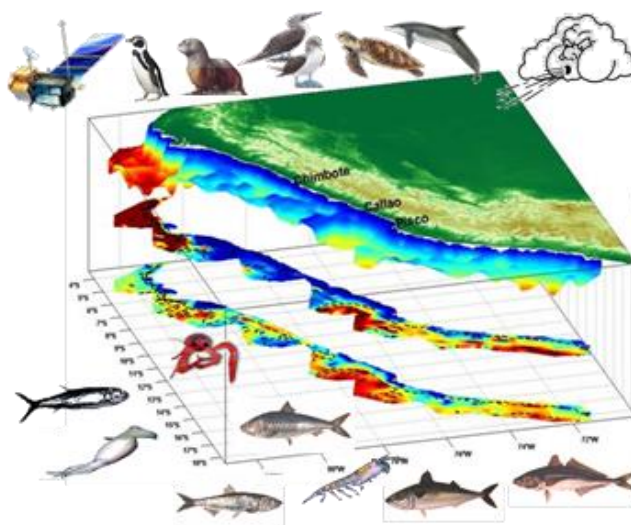
NATIONAL FISHERIES SOCIETY – SCIENTIFIC RESEARCH COMMITTEE  
HUMBOLDT INSTITUTE OF MARINE AND AQUACULTURE RESEARCH

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  
New Zealand (hosted remotely), 3-8 October 2020

### Changes in the habitat of Jack mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*) in Peruvian jurisdictional waters between 2018 and 2020



Mariano Gutiérrez, Salvador Peraltila, Daniel Grados, Rodolfo Cornejo, Ana Alegre, Martín Santivañez, Carlos Valdéz, Susan Montero, Lucero Moreno, Anibal Aliaga

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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## Summary

The 8<sup>th</sup> Workshop on the habitat Jack mackerel and other species of the Peruvian Current in the Humboldt System was held in Lima from July 6 to 10, 2020. The objectives of the workshop focused in the changes in the habitat the last 3 years (2018 – 2020). The data and analysis in this paper are focused only in the areas of operation of the Peruvian industrial fleet in the Peruvian jurisdictional waters and, therefore, refer only to the northern part of the Peruvian Current, within Peruvian jurisdictional waters. The reports of the past seven workshops are listed in the “References” section of this document.

It has been observed that during summer 2020 the presence of Jack mackerel and chub mackerel has occurred concurrently in oceanic waters with relatively high temperatures, in surface subtropical water masses, which is unusual at least for the season; the usual is its presence in mixed waters.

From the analysis of the various variables regarding the habitat of Jack mackerel and chub mackerel, it is concluded that there is no a single pattern for each season, at least for summer, which is the most important fishing season of the year. In other words, significant differences have been found between the summer months of the years that have been analyzed (2018-2020).

It has been found that, at least for years 2019 and 2020, that chlorophyll was not a significant parameter to explain the distribution of Jack mackerel, since it is always observed with low concentration values. On the other hand, Jack mackerel had a shallow distribution during summer of 2020 compared to the summer 2019, therefore it was more aggregated and available to fishing during 2020.

On the other hand, the use of the Jack mackerel potential habitat model (MHPJ) showed that Jack mackerel habitat presented large changes in its latitudinal and longitudinal distribution during 2018, 2019 and 2020.

Likewise, the distribution of Jack mackerel and *vinciguerria* presented a similar spatial structure (variogram) during summers of 2019 and 2020, which could be a key aspect to study regarding the habitat of jack mackerel. A similar observation was made previously with respect to the years 2018 and 2019.

Regarding the size distribution of Jack mackerel, during the summer of 2018 it was observed a strong modal group of 28 cm, which was again observed by the purse-seine fleet in the years 2019 and 2020. Chub mackerel also registered a modal group of 28 cm which was observed until spring 2019; This group was not observed in the summer of 2020, and instead that year the entry of a new modal group of 30 cm was observed.

## 1. Introduction

The Scientific Research Committee (“CIC” for its acronym in Spanish) of the National Fisheries Society (“SNP” for its acronym in Spanish), in cooperation with the Humboldt Institute for Marine and Aquaculture Research (IHMA by its acronym in Spanish), organized the Eighth SNP Workshop on the habitat conditions of Jack mackerel and other species of the Current of Peru in the Humboldt System, which was carried out from July 6th to 10th, 2020 with the active participation of the Peruvian Institute of Marine Research (“IMARPE”, for its acronym in Spanish).

This 8<sup>th</sup> Workshop is a contribution to the national and international effort to research and diagnose the current population situation of Jack mackerel, as well as other fishing resources of the South Pacific, with special emphasis on aspects related to their habitats. These types of workshops have been developed since 2011. The reports of the past seven workshops are listed in the “References” section of this document.

For the present case, the oceanographic, biological and fishing information collected by the companies affiliated to SNP between 2018 to 2020 has been analyzed. Unfortunately, due to the official provisions and restrictions regarding the pandemic crisis this year, it has not been possible to access the complete acoustic data that has been collected by the fishing fleet during the summer 2020.

This document describes the environmental changes observed for certain variables between 2018 and 2020, and presents various analyzes carried out with respect to Jack mackerel (*Trachurus murphyi*), chub mackerel (*Scomber japonicus*), vinciguerría (*Vinciguerría lucetia*) and various top predator’s species based on information provided by the companies affiliated to SNP. The data has been analyzed with the cooperation between scientists from IMARPE, the IHMA and the CIC of the SNP.

The analysis and results shown in this document are referred to the areas of operation of the Peruvian industrial fleet in the waters under Peruvian national jurisdiction, between 2018 and 2020. The several references to the “Peruvian Current” in this document are, therefore, mostly referred to the portion of the Peruvian Current within Peruvian jurisdictional waters.

## 2. Description of the habitat of Jack mackerel and chub mackerel of the Peruvian Current in the Humboldt System between 2018 and 2020

Various oceanographic parameters are presented for the years 2018, 2019 and 2020 with an indication of the fishing sets for Jack mackerel and chub mackerel (represented by symbols). Figure 2.1.1 shows, from left to right, the mean oceanographic parameters for January, February, and March of each corresponding year, in order to appreciate the seasonal changes that occurred in the last three years and its possible relation with the distribution and relative abundance of Jack mackerel and chub mackerel.

### 2.1. Sea surface temperature between 2018 and 2020

In the described period, the presence of Jack mackerel and chub mackerel has been observed along the thermal fronts, except for the months of February and March 2020, in which the presence of both species has occurred in open ocean waters (surface subtropical waters). Likewise, the Jack mackerel fishing sets were always made outside the continental shelf. It is considered that, in general, the moderate thermal conditions of the last three years have led to a higher aggregation of Jack mackerel, especially in the southern zone. Chub mackerel, on the other hand, has tended to be distributed towards the north due to the equatorial waters that predominated in that area (Figure 2.1.1).

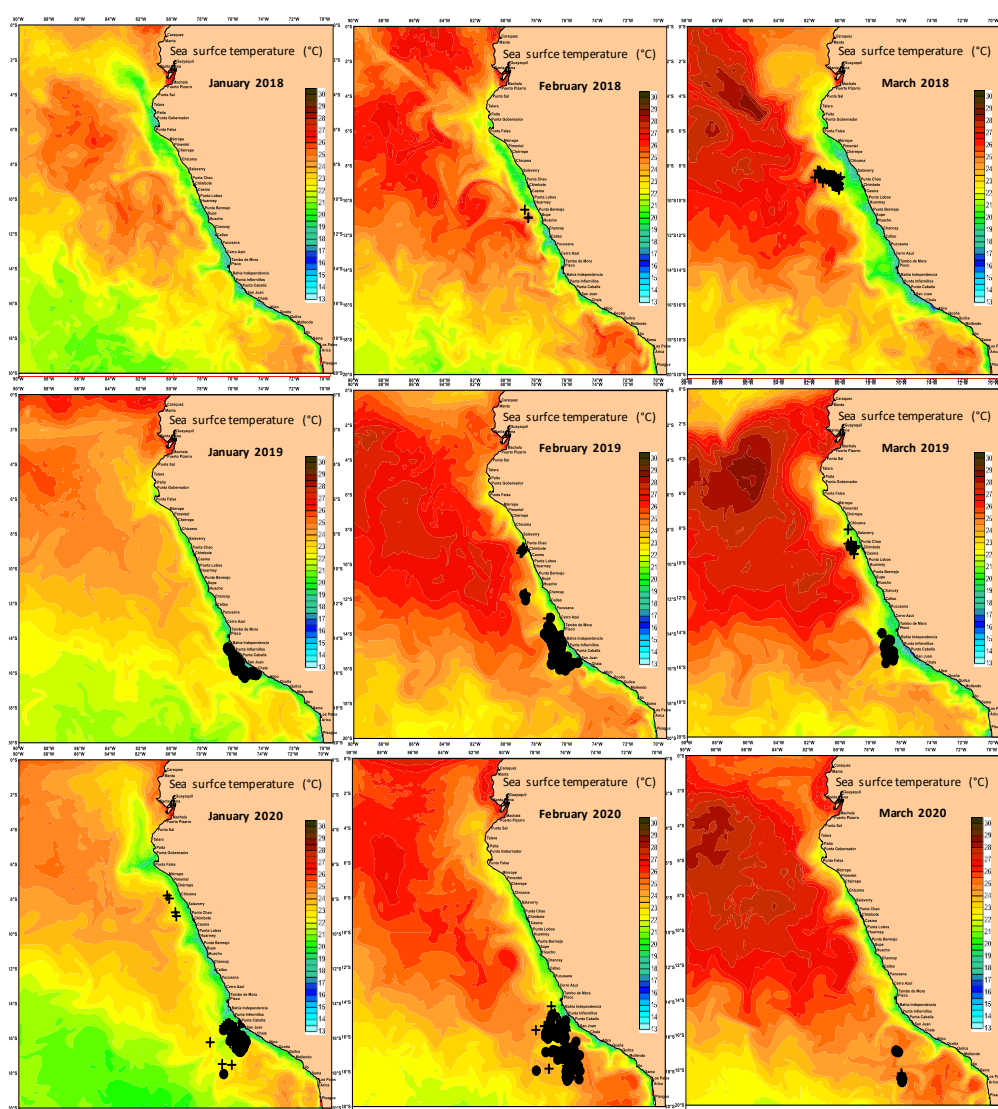


Figure 2.1.1. Mean Sea surface temperature (SST, °C) during summers months of 2018, 2019 and 2020. Fishing sets for Jack mackerel and chub mackerel are indicated by circles in the case of Jack mackerel and by crosses in the case of chub mackerel.

## 2.2. Sea surface temperature anomaly (SSTA, °C)

The summer of 2018 was characterized by high negative SSTA values that cover a large part of the coast; These anomalous conditions do not configure a suitable habitat for Jack mackerel but for chub mackerel in the north, as it is usually observed. The year 2019 had a summer characterized by relatively high thermal anomalies in the southern zone but with a coastal strip with normal to slightly cold conditions, which generated a favorable thermal front for both Jack mackerel and chub mackerel. The year 2020 had a summer characterized by slightly negative thermal anomalies along the entire coast. It is under these conditions that the largest presence of Jack mackerel and chub mackerel has occurred on a vast nucleus with positive thermal anomalies in the southern zone (Figure 2.2.1).

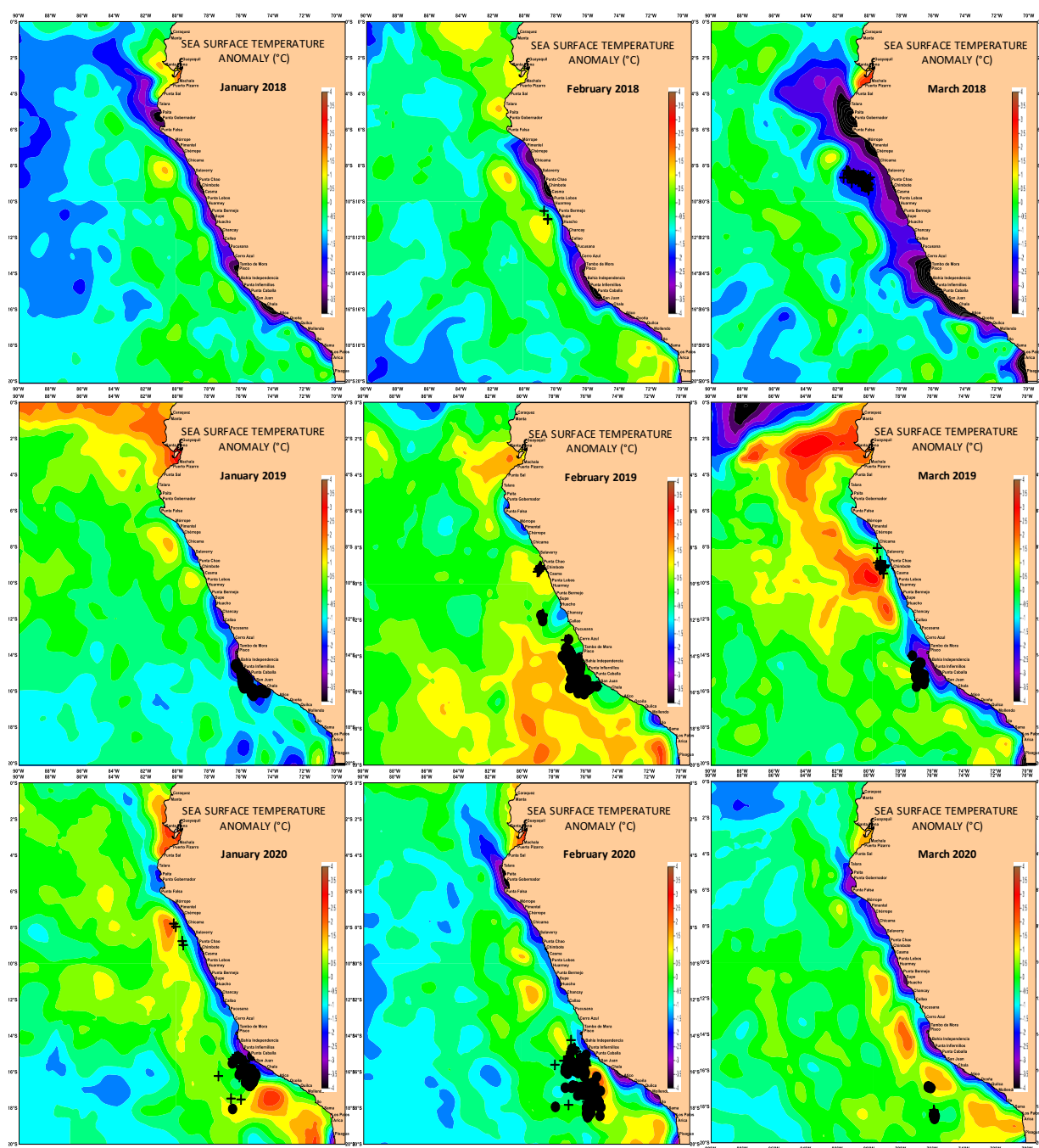


Figure 2.2.1 Mean Anomalies of the Sea Surface Temperature (SSTA, °C) during the summer months in 2018, 2019 and 2020. Fishing sets for Jack mackerel and chub mackerel are indicated by circles in the case of Jack mackerel and by crosses in the case of chub mackerel.

### 2.3. Sea surface salinity (SSM, ups)

During summer of years 2018 and 2019, the presence of Jack mackerel and chub mackerel was observed in areas with mixed waters between Subtropical Surface Waters (ASS), Surface Equatorial Waters (AES) and Cold Coastal Waters (ACF) along the coast. In general, there is a larger presence of chub mackerel in the north and Jack mackerel in the south. During summer of 2020, a predominance of ASS is observed in the south, where the highest aggregations of Jack mackerel and chub mackerel were found. In other words, between February and March 2020, these two species have been observed in conditions that are not typical of their distribution and behavior during the summer season (Figure 2.3.1).

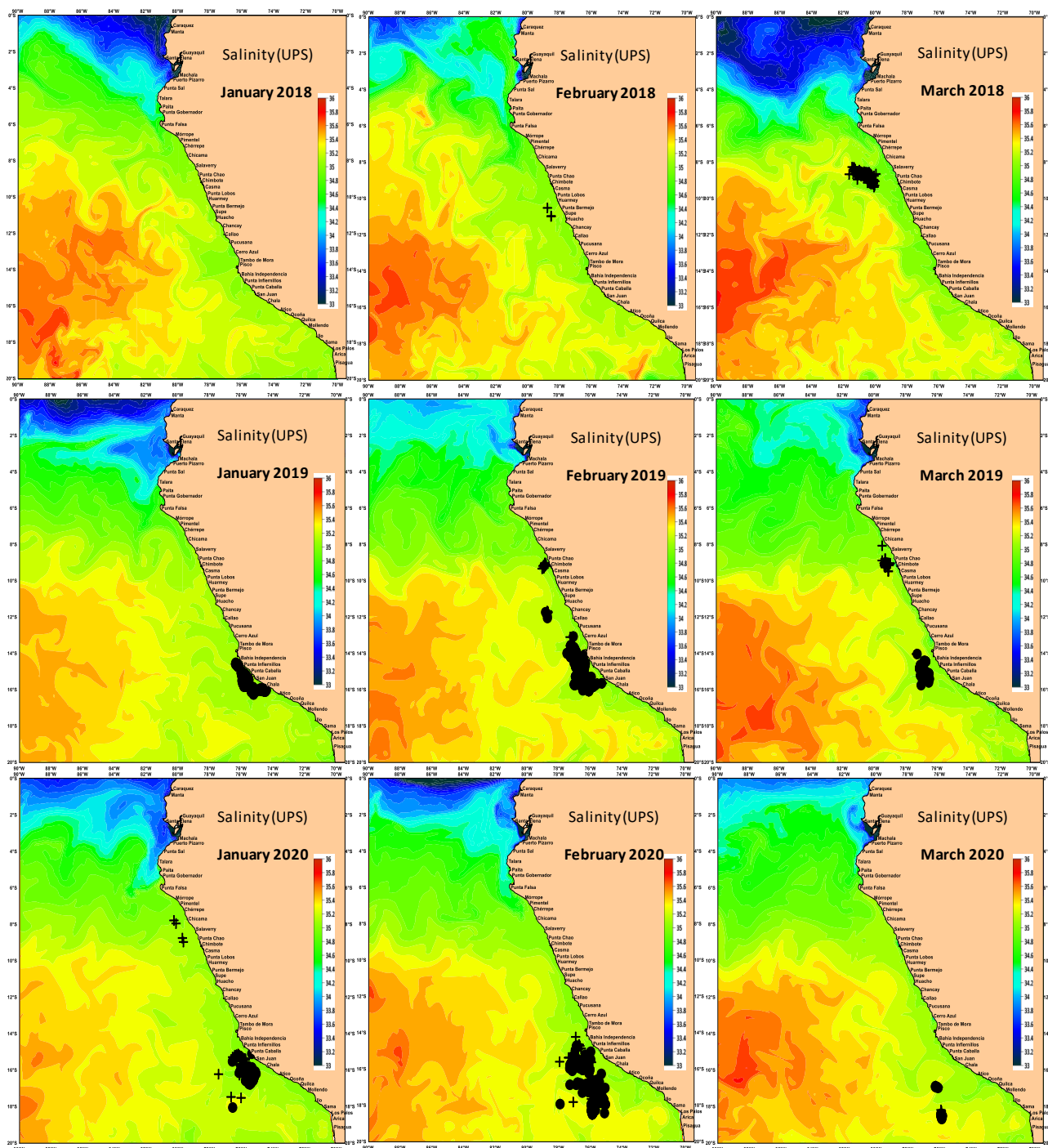


Figure 2.3.1 Mean Sea Surface Salinity (ups) during summer months of years 2018, 2019 and 2020. Fishing sets for Jack mackerel and chub mackerel are indicated by circles in the case of Jack mackerel and by crosses in the case of chub mackerel.

## 2.4. Sea surface chlorophyll-a (ug / Lt)

The summer during 2018 was characterized by high concentrations of chlorophyll in the northern and central zones, which, however, did not mean a larger aggregation of Jack mackerel or chub mackerel. In the summer of 2019, a lower concentration of chlorophyll was observed, and on that occasion Jack mackerel and chub mackerel were found on the outer edges of the highest concentration of chlorophyll in the southern zone. The summer of 2020 was characterized by high concentrations of chlorophyll, but this time the preference for Jack mackerel and chub mackerel was in oceanic waters and not at the edges of the coastal upwelling (Figure 2.4.1).

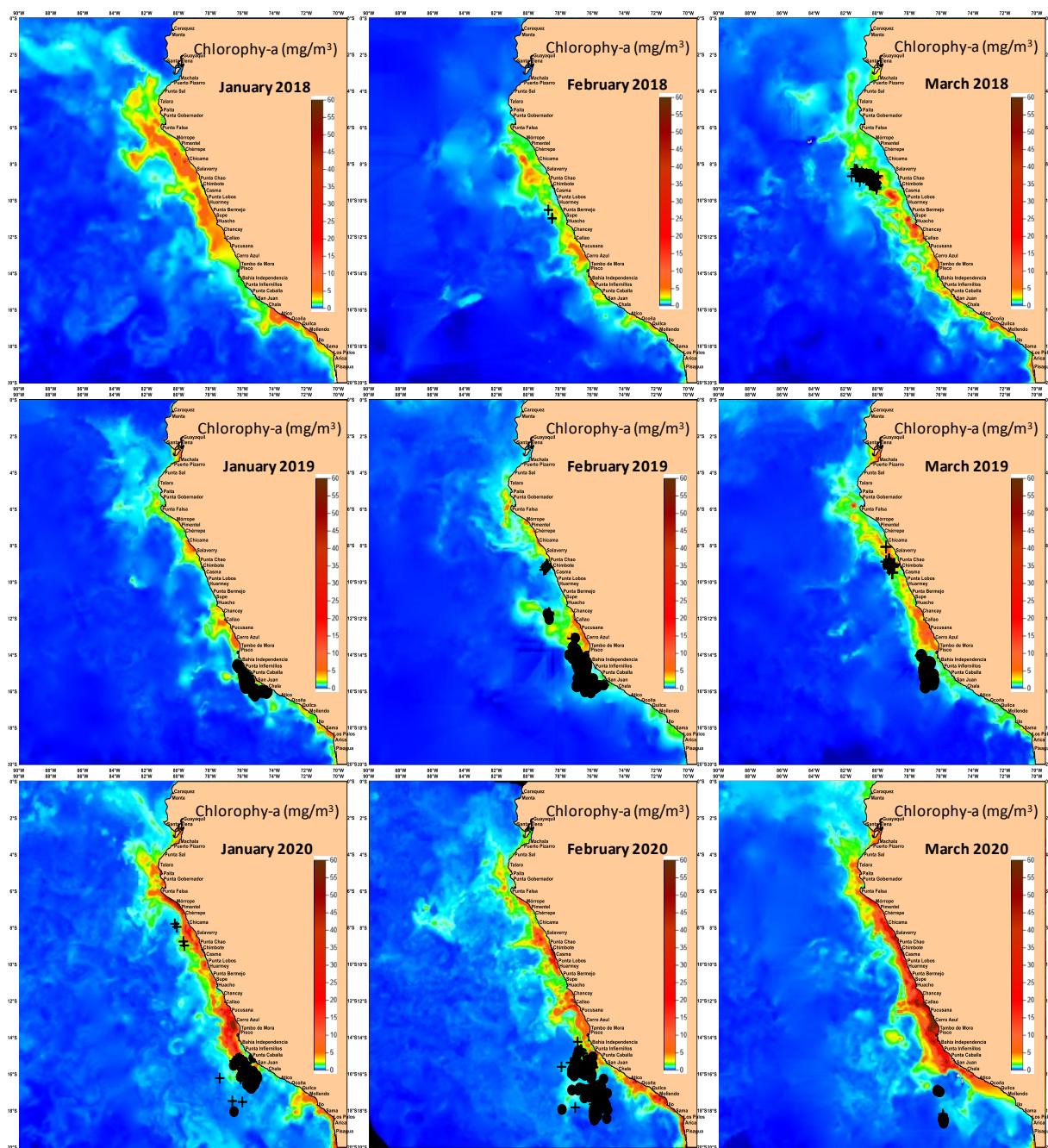


Figure 2.4.1. Mean Concentration Surface Chlorophyll of the Sea (mg/m<sup>3</sup>) during summer months of years 2018, 2019 and 2020. Fishing sets for Jack mackerel and chub mackerel are indicated by circles in the case of Jack mackerel and by crosses in the case of chub mackerel.

## 2.5. Sea Level Anomaly (SLA, cm)

The summer of 2018 was characterized by a low dynamic activity in addition to a greater contribution of surface Ecuadorian waters (“AES” for its acronym in Spanish) in the northern area, which configures a more suitable habitat for chub mackerel. Instead, the summer months of 2019 and 2020 presented an intense dynamic, which is associated with a larger presence of Jack mackerel and chub mackerel, but mainly in the southern area. More specifically, the presence of Jack mackerel and chub mackerel have been related to intermediate SLA values (Figure 2.5.1).

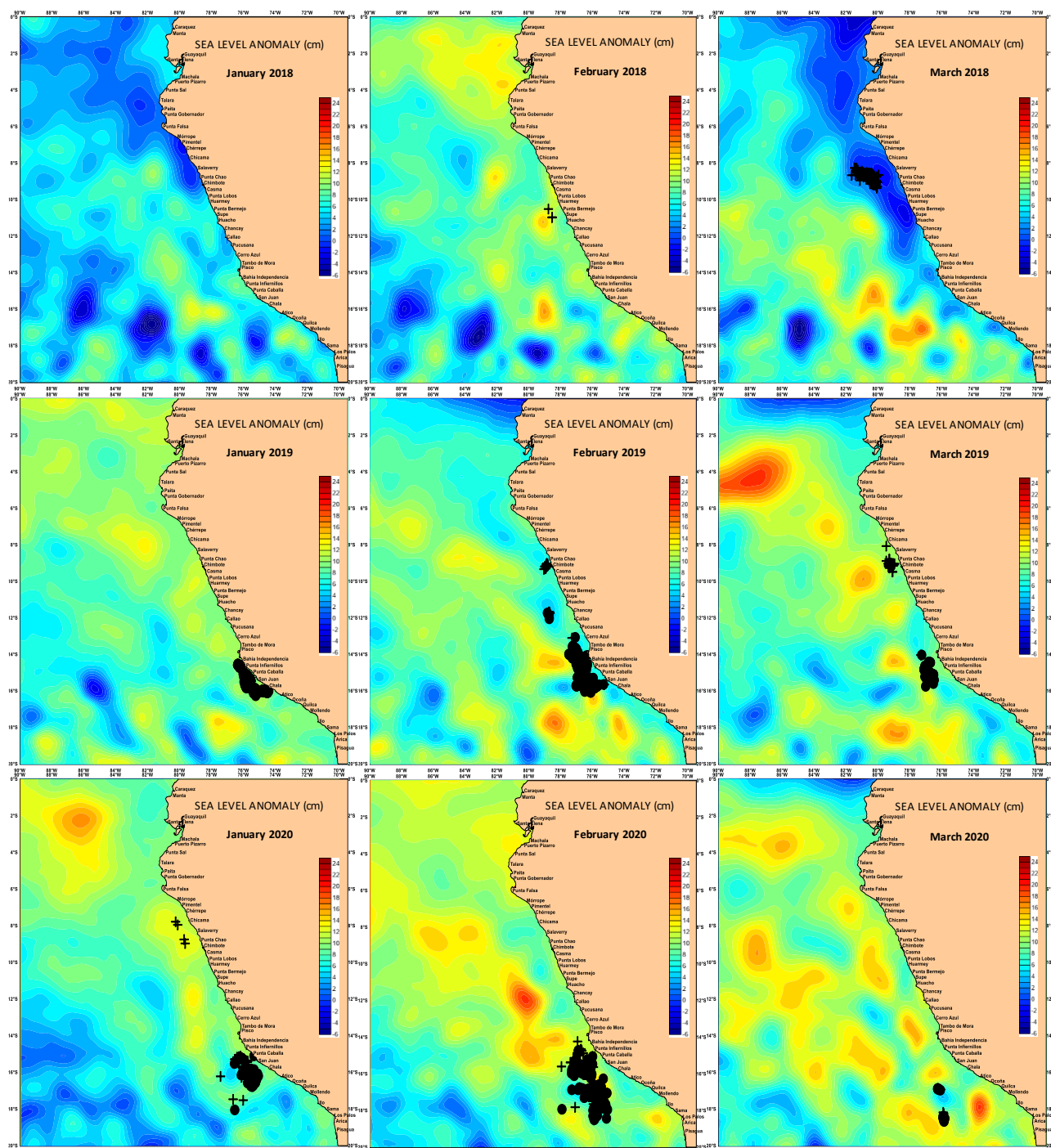


Figure 2.5.1. Mean Anomaly of the Sea Surface (cm) during the summer months of years 2018, 2019 and 2020. Fishing sets for Jack mackerel and chub mackerel are indicated by circles in the case of Jack mackerel and by crosses in the case of chub mackerel.

### 3. Analysis of variability of parameters for Jack mackerel and chub mackerel species during the years 2018, 2019 and 2020.

Figures 3.1 and 3.2 show the compared results of the variability analysis of parameters relevant to the distribution of Jack mackerel and chub mackerel species during years 2018, 2019 and 2020. The analyzed parameters are: Sea Surface Temperature (SST, ° C), Sea Surface Temperature Anomaly (ATSM, ° C), Sea Surface Salinity (SSM, ups), Chlorophyll (ug / Lt), Surface Level Anomaly (SLA, cm), Sea Surface Altimetry (ASM, cm), latitude, distance from the coast and month of the year.

The case of Jack mackerel is shown in Figure 3.1., which shows noticeable differences between various parameters for years 2018 to 2020. For SST a wide range of thermal values is appreciated (between 16 and 25 °C), with a preference for relatively low temperatures during 2018, and for a wide thermal range during 2019 and with relatively high values during 2020. However, the distribution of Jack mackerel is clearly related to a limited range of ATSM (between -1 to +1 °C), SSM (35 to 35.2 ups) and low chlorophyll concentration values. Regarding SLA and ASM, the presence of Jack mackerel is confined almost entirely to positive values, but not beyond values of 12 cm. Latitudinally, the distribution of Jack mackerel presented a wide range during 2018, but it was mainly present on the central coast during 2019 and on the south coast during 2020. Regarding its distribution according to its distance from the coast, Jack mackerel was at relatively close distances during 2018 and 2019, but it has increased notably during 2020. Finally, the timing of the distribution of fishing sets on Jack mackerel is related to national fisheries management, specifically according to the development of the anchovy fishing seasons.

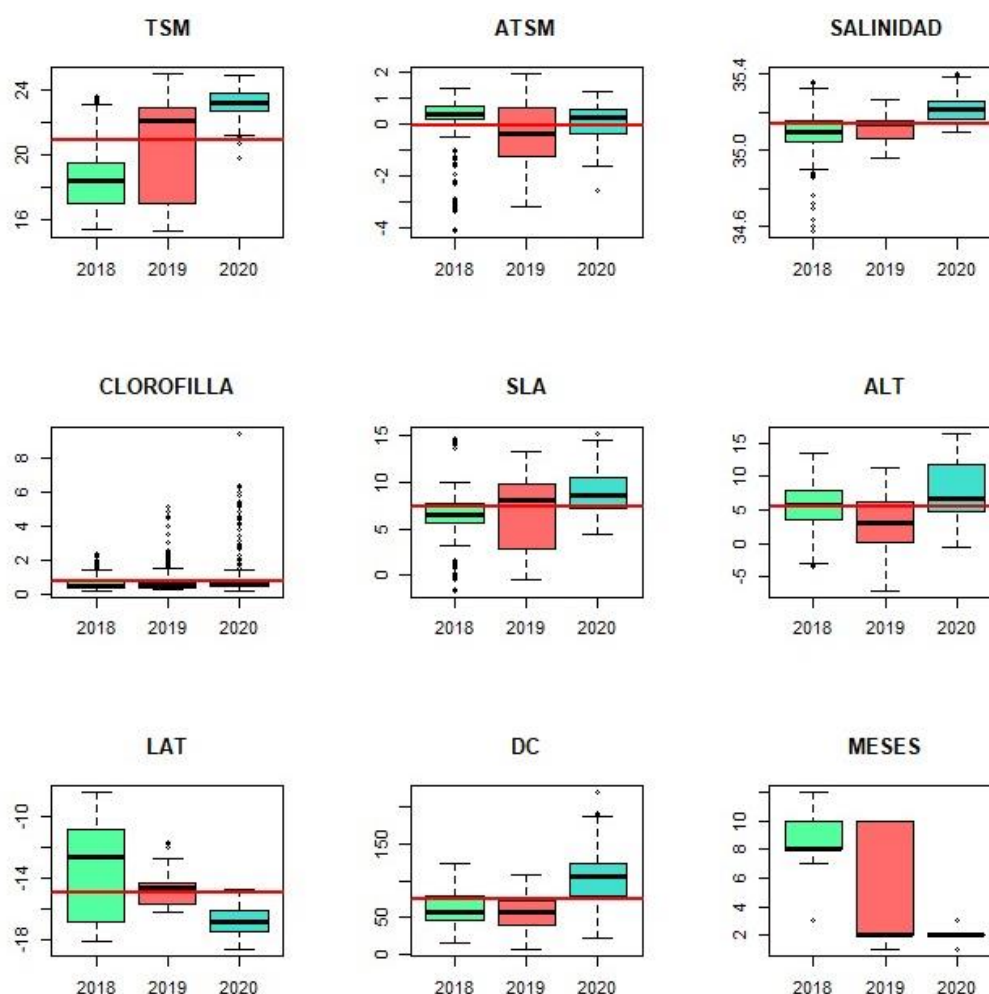


Figure 3.1. Analysis of variability (box plot) related to the distribution of Jack mackerel between years 2018, 2019 and 2020. (Salinidad=sea surface salinity; ALT= sea surface altimetry; LAT=latitude; DC=distance off coast; meses=months).

In the case of chub mackerel Figure 3.2. shows some differences, but also similarities between various parameters between years 2018 to 2020. In the case of SST a limited range of thermal values is appreciated (between 20 and 25°C), which in general was maintained in the three years analyzed. However, the distribution of chub mackerel is related to a rather wide range of ATSM (between -4 to +2 °C) and SSM (34.7 to 35.2 ups), though with low values of chlorophyll. Regarding SLA and ASM, the presence of mackerel is confined almost totally to positive values, but not beyond values of 12 cm. Latitudinally, the distribution of chub mackerel was limited to the north during 2018, then it had a wide distribution during 2019, and was mainly distributed in the south during 2020. Regarding its distribution according to its distance from the coast, chub mackerel was relatively distant during 2018, near the coast in 2019, and again distant in 2020. Finally, the timing of the chub mackerel distribution of fishing sets, since it is the same fleet that target Jack mackerel and anchovy, is directly related to national fisheries management, specifically regarding the anchovy fishing seasons; This is how the fishing season for Jack and chub mackerel takes place mainly during summer months, which is when there is no anchovy season in place.

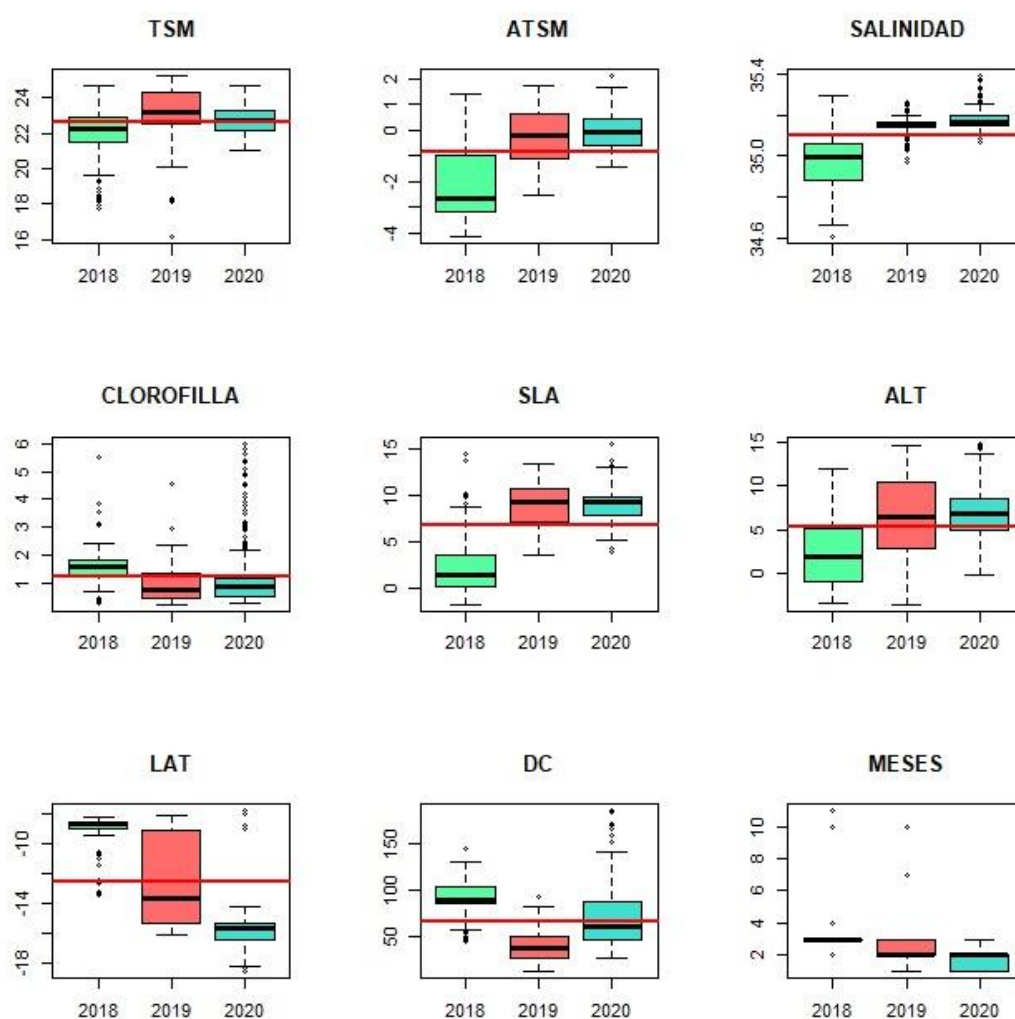


Figure 3.2. Analysis of variability (box plot) of several parameters related to the presence of mackerel between the years 2018, 2019 and 2020. (Salinidad=sea surface salinity; ALT= sea surface altimetry; LAT=latitude; DC=distance off coast; meses=months).

## 4. Description of Jack mackerel and chub mackerel abundance in relation to ocean dynamics using acoustic and geostatistical techniques.

A geostatistical method has been used to integrate the analysis of catches obtained through all fishing sets made between 2019 and 2020, for both Jack and chub mackerel. They have been calculated the centers of gravity and inertia associated with each of 8 pre-defined zones along the coast. The information was also grouped into fortnights (29 fortnights from January 2019 to March 2020) and the average catch per zone and fortnight was used as an indicator or proxy of fish density (tons/mn<sup>2</sup>). Thus, the multiplication of the average catch by inertia yields an abundance in tons, which is assumed proportional to biomass only in the areas where the fleet has operated. Details of the used methodology for data analysis are described in SNP<sup>1</sup> (2015).

### 4.1. Abundance of Jack mackerel (*Trachurus murphyi*)

Information on latitudinal acoustic biomass and annual Jack mackerel catches along the Peruvian coast has been updated. IMARPE's acoustic surveys data has been used for this purpose and annual landing data has been collected from the Ministry of Production's website ("PRODUCE" for its acronym in Spanish). Figure 4.1.1. presents a Hovmoller diagram of changes in acoustic Jack mackerel biomass between 1983 and March 2020. Two regimes are observed: one between 1983 and 2002, in which biomass fluctuated between medium and high levels, and another regime exists after 2002 with abundances varying between medium and low levels. However, in recent years there has been a positive trend in biomass, i.e. increase towards average levels of abundance. Catches in the same period (1983-2020) are also show, in general, with better yields when biomass has been higher.

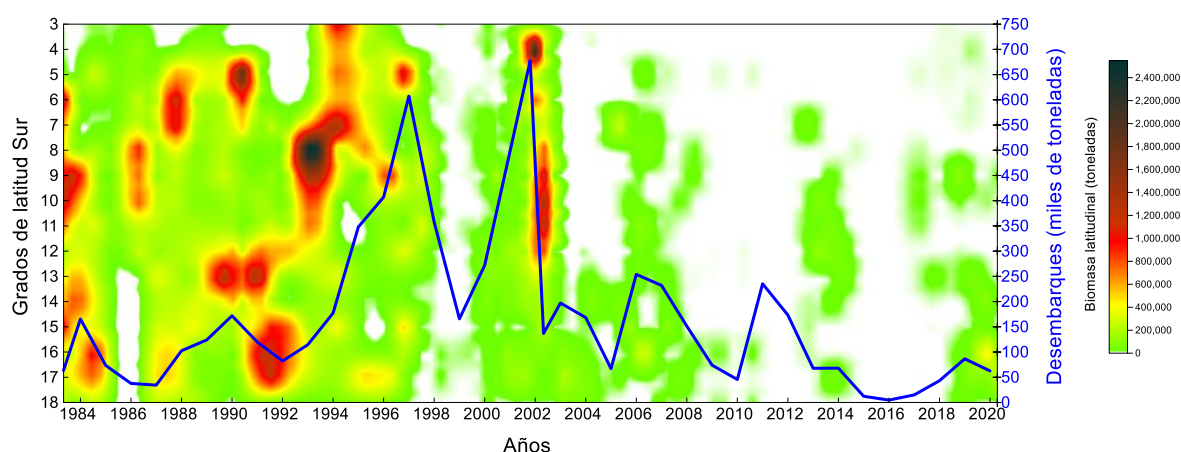


Figure 4.1.1. Latitudinal acoustic biomass of Jack mackerel along the Peruvian coast represented by the vertical axis on the left between 1983 and 2020 (horizontal axis). Catches are represented by the blue line and the right vertical axis. Colors correspond to biomass according to the legend on the right side of the figure.

#### 4.1.1. Jack mackerel abundance calculated by geostatistical methods

Figure 4.1.1.1. Presents the location and distribution of fishing sets that have been made for jack mackerel between January 2019 and March 2020. The industrial fishing quota for Jack mackerel, of 70 thousand tons, was granted by PRODUCE for 2020 (RM N° 025-2020-PRODUCE), and completed by March. The sets have been classified by geographical areas (8) and by fortnights, in order to calculate the average catch (tons/mn<sup>2</sup>) as a proxy of density. Also they have been calculated the Center of Gravity (latitude, longitude) and inertia (mn<sup>2</sup>) in each one of regions/periods. Abundance refers to the number of fish counted in units of mass only

<sup>1</sup>SNP (2015). VI Diagnostic SNP Workshop on Jack Mackerel (*Trachurus murphyi*). Acoustic, geostatistical and biometric analysis protocols used in the diagnosis of the population status of Jack mackerel. Scientific Research Committee of the National Fisheries Society. Lima, 109 pp.

in the areas of operation of the fleet. The abundance is calculated by multiplying the average catch obtained in each fortnight by its corresponding inertia.

Jack mackerel fishing sets have been observed off the continental shelf, from 10 to 190 miles offshore, and between latitudes 11 ° 30'S (Chancay) and 18 ° 20'S (Sama). 1,858 sets have been made, with catches ranging from 5 to 680 tons per set. The average catch was 95.5 tons per set. 177,252 tons of Jack mackerel have been caught between January 2019 and March 2020. The average monthly was 8,438 tons.

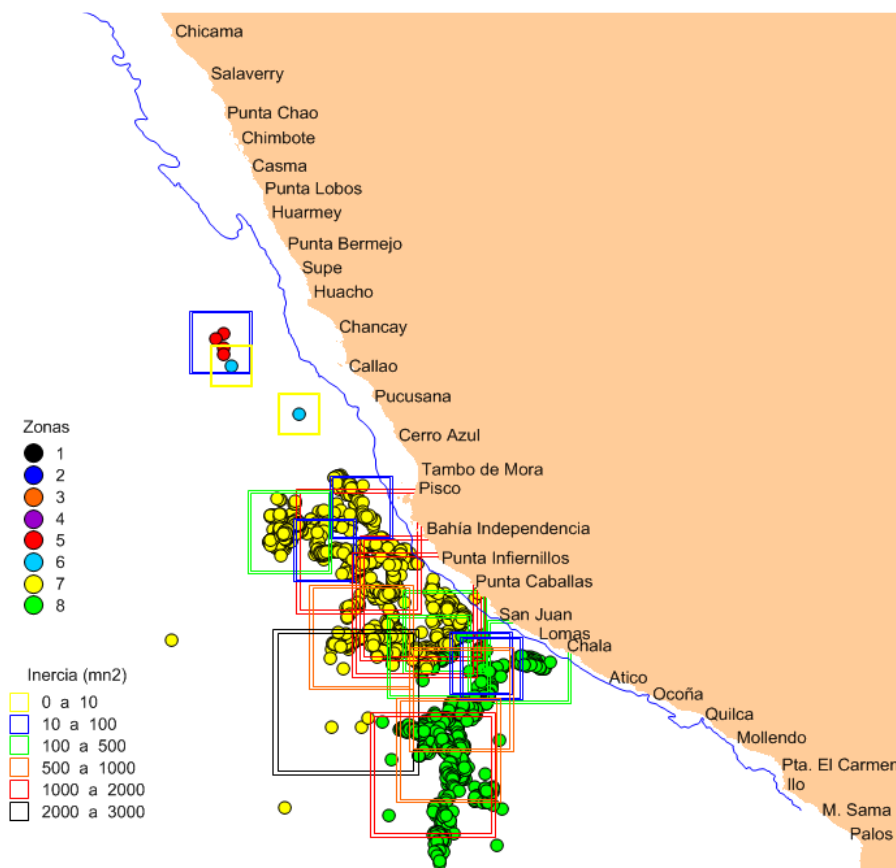


Figure 4.1.1.1. Distribution of jack mackerel fishing sets between January 2019 and March 2020. Fishing sets have been classified by Zones (1 to 8) and by fortnight. The Centers of Gravity (indicated by crosses) and the magnitude of inertia in each zone and fortnight have been calculated in order to estimate the abundance of Jack mackerel.

Table 4.1.1.1. and figure 4.1.1.2. show catches and estimated abundances of jack mackerel as well as the ratio Catch/Abundance between January 2019 and March 2020. Months with zero catch or abundance are due to the fact that the fleet was operation in the anchovy fishery.

The highest abundance of jack mackerel was estimated during February 2019, with 512 thousand tons, followed by March 2020 with 396 thousand tons. The lowest abundance was estimated in October 2019 with only 4 thousand tons. The mean ratio between catches and abundance was 14%, it expresses that catches has been one sixth of the calculated abundance. These calculations of jack mackerel abundance had a coefficient of variation of 24%.

The highest calculated inertia for jack mackerel (distribution area) in the zones where the fleet operated was 4,159 mn2 during March 2020 and the lowest was 71 mn2 during October 2019. The month average value of the distribution area has been calculated as 1,307 mn2.

Table 4.1.1.1. Abundance and catch (tons) of jack mackerel between January 2019 and March 2020, indicating the proportion (percentage) of the abundance that has been caught.

Month	Abundance (t)	Catch (t)	Ratio
January 2019	40.427	11.831	0.29
February	511.813	60.372	0.12
March	91.079	14.778	0.16
April			
May			
June			
July			
August			
September			
October	10.799	9.811	0.91
November	4.066	4.464	1.10
December			
January 2020	297.876	2.857	0.01
February	255.772	49.541	0.19
March	396.109	23.597	0.06

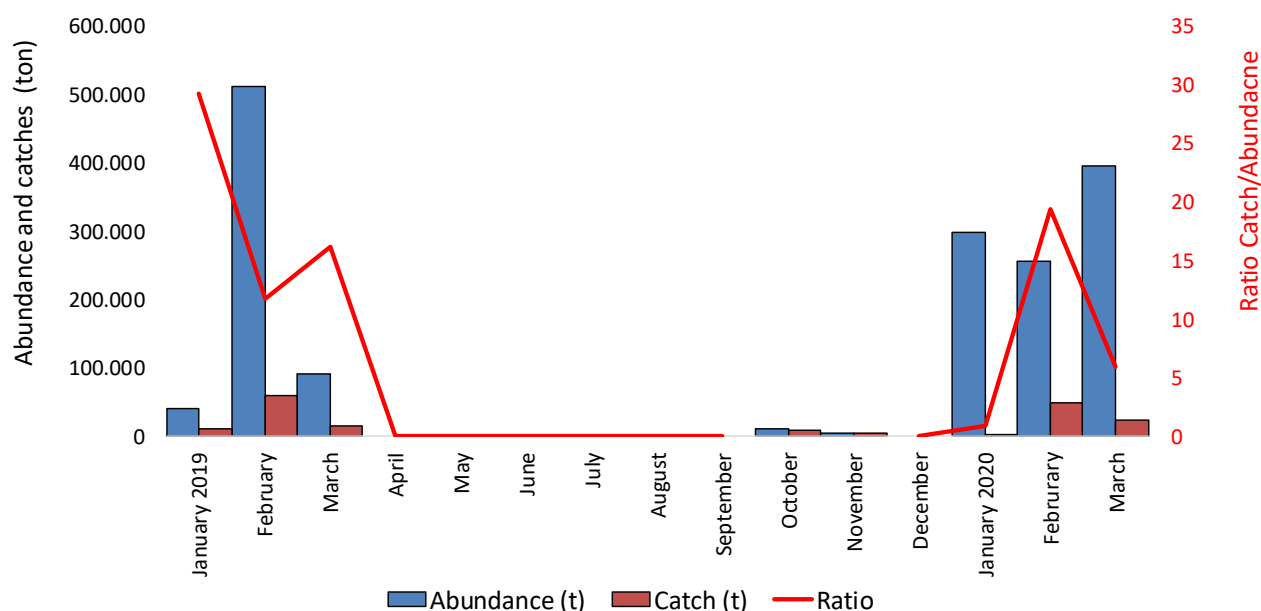


Figure 4.1.1.2. Abundance and catch (tons) of jack mackerel between January 2019 and March 2020, indicating the ratio (percentage) of the abundance that has been caught

#### 4.2. Abundance of chub mackerel (*Scomber japonicus*)

It has been updated the information on latitudinal acoustic biomass and annual chub mackerel catches along the Peruvian coast using IMARPE's acoustic surveys data. The annual landing data has been collected from the website of PRODUCE. Figure 4.2.1. presents a Hovmoller diagram of the changes in chub mackerel latitudinal biomass between 1983 and 2020. In general, three regimes for chub mackerel abundance are observed: the first occurred between 1983 and 1992 in which the biomass presented a uniform distribution throughout the entire coast, although with medium abundances; the second period occurred between 1992 and 2002 in which the biomass fluctuated between medium and high levels; and a third regime exists after 2002 with abundances varying between medium and low levels. However, in recent years there has been a positive trend in biomass, that is, an increase of the biomass towards medium levels of abundance. The catches in the same period (1983-2020) show, in general, better yields in the years in which the biomass has been higher.

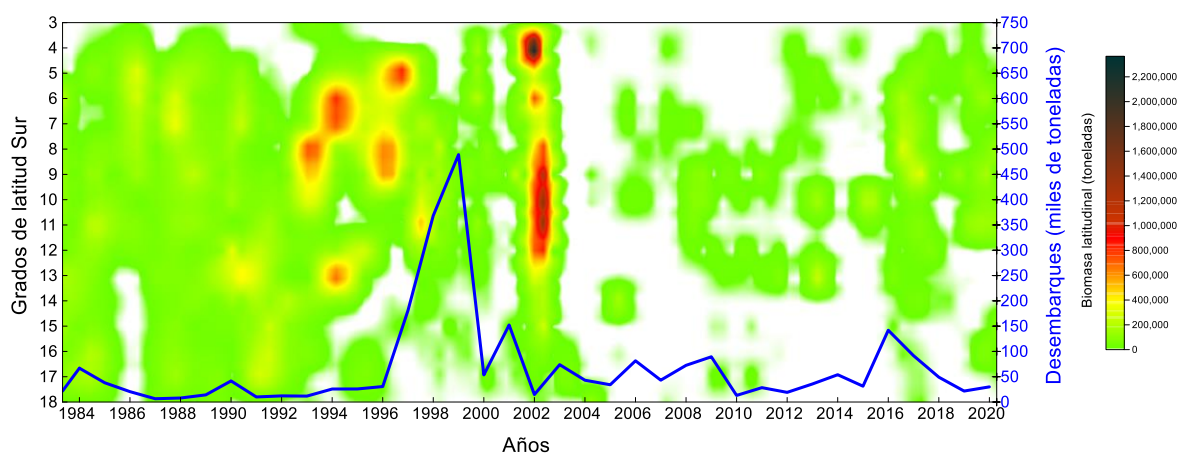


Figure 4.2.1. Latitudinal chub mackerel biomass along the Peruvian coast. Latitude is represented by the vertical axis on the left between 1983 and 2020 (horizontal axis). The catches are represented by the blue line and the right vertical axis. The colors correspond to biomass according to the legend on the right side of the figure.

#### 4.2.1. Chub mackerel abundance calculated by geostatistical methods

Figure 4.2.1.1 shows the location and distribution of the chub mackerel fishing sets that have been made between January 2019 and March 2020. The chub mackerel 2020 fishing quota granted by PRODUCE for the industrial fleet is 75,200 thousand tons (RM N° 025-2020-PRODUCE), of which 48,556 thousand had been caught by March 2020. The fishing sets have been classified by geographical areas (8) and by fortnights, in order to calculate the average catch (tons/mn<sup>2</sup>) as a proxy of fish density, the Center of Gravity (latitude, longitude) and inertia (mn<sup>2</sup>) in each one of zones/time interval. Abundance refers to the number of fish counted in units of mass in the areas of operation of the fleet. The abundance is calculated by multiplying the average catch obtained in each fortnight by its corresponding inertia.

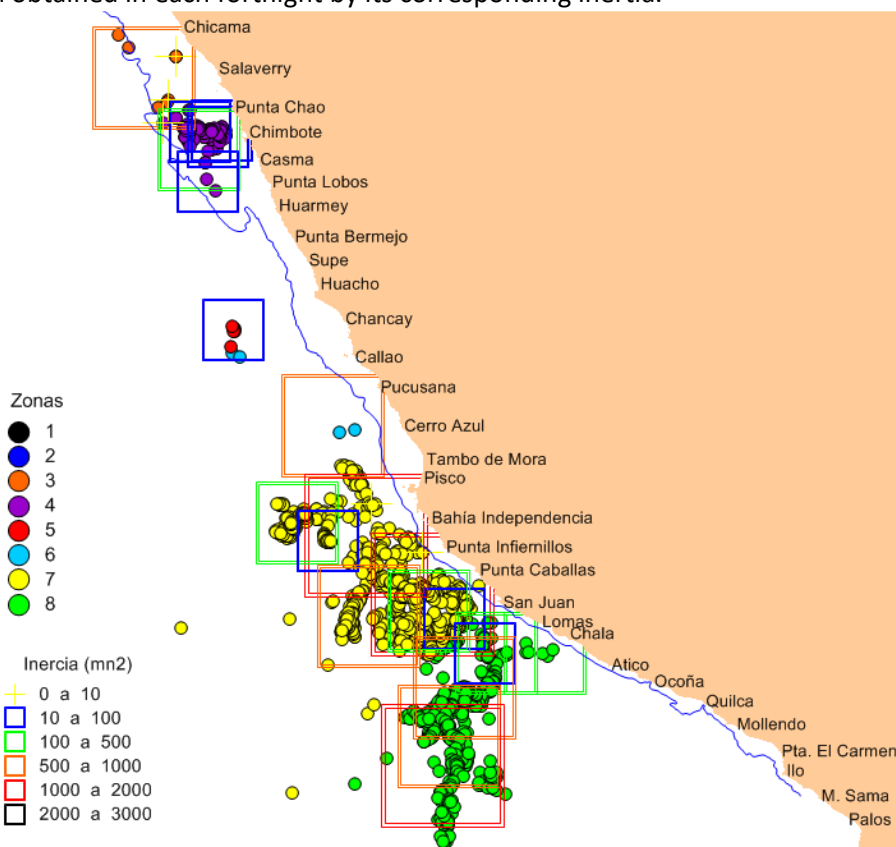


Figure 4.2.1.1. Distribution of chub mackerel fishing sets between January 2019 and March 2020. Fishing sets have been classified by Zones (1 to 8) and by fortnight. The Centers of Gravity (indicated by crosses) and the

magnitude of inertia in each zone and fortnight have been determined in order to estimate the abundance of mackerel.

Chub mackerel fishing sets have been observed out of the continental shelf, from 10 to 190 miles offshore, and between latitudes 8°00'S (Chicama) and 18°20'S (Sama). Between January 2019 and March 2020, 1,401 sets had been made, with catches ranging from 3 to 576 tonnes per set. The average catch per set was 63.15 tons, and 88,472 tons of chub mackerel have been caught between January 2019 and March 2020.

The fortnight with the highest chub mackerel catch was the first in February 2020 with 20,801 tons, and the lowest catch was reported in the second half of September 2019 with 17 tons. The average monthly catch in the indicated period was 5,898 tons.

In table 4.2.1.1 and figure 4.2.1.2. The catches and abundances of chub mackerel calculated with the geostatistical method (tons) are observed, as well as the ratio between both quantities between January 2019 and March 2020. It should be noted that the lack of estimates in certain months is due to the fact that the fishing vessels were participating in the anchovy fishing seasons.

The highest abundance of chub mackerel was estimated during February 2019, with 404 thousand tons, followed by March 2020 with 342 thousand tons. The lowest abundance was estimated in July 2019, with 2 thousand tons. The average relationship between catches and abundance was 10.5%, that is to say that the amount caught has been one tenth of the available abundance. The coefficient of variation of these calculations is 35%.

The highest calculated inertia of chub mackerel distribution area where the fleet operated was 6,775 mn2 during March 2020, and the lowest was 18 mn2 during July 2019. The average value of the distribution area is 1,425 mn2.

**Table 4.2.1.1. Abundance and catch (tons) of chub mackerel between January 2019 and March 2020, indicating the ratio (percentage) of the abundance that has been caught.**

Month	Abundance (t)	Catch (t)	Ratio (%)
January 2019	16.300	2.867	0.18
February	403.858	21.327	0.05
March	85.014	9.825	0.12
April			
May			
June			
July	1.725	420	0.24
August			
September	0	17	
October	7.725	4.164	0.54
November	2.618	1.296	0.49
December			
January 2020	25.980	1.063	0.04
Februrary	174.136	38.651	0.22
March	341.519	8.842	0.03

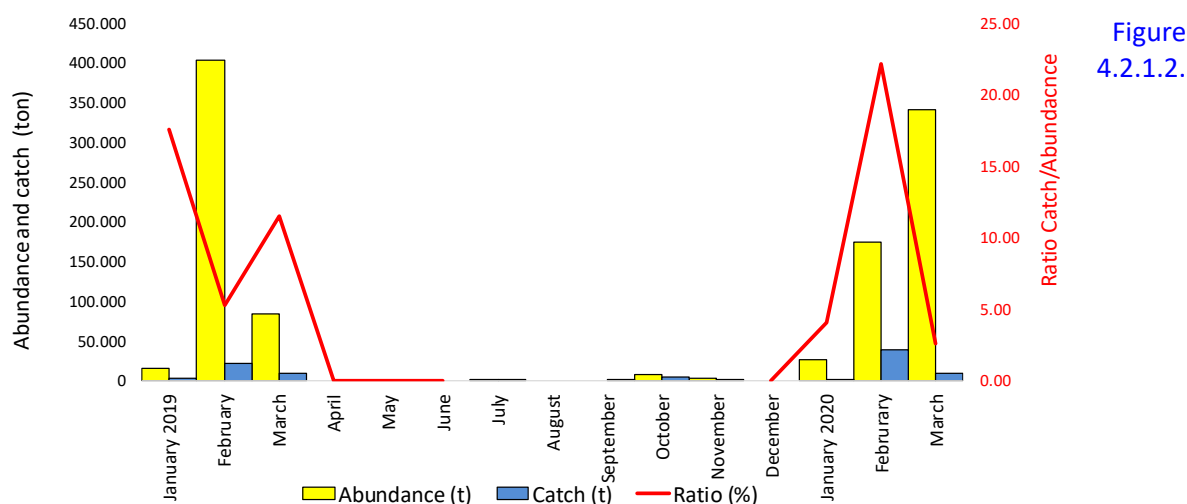


Figure  
4.2.1.2.

Abundance and catch (tons) of chub mackerel between January 2019 and March 2020, indicating the proportion (percentage) of the abundance that has been caught

#### 4.3. Distribution of jack mackerel in relation to vinciguerria lanternfish (*Vinciguerria lucetia*).

For a few years it has been identified that a species closely related to jack mackerel is vinciguerria and mesopelagic fish species in general. Unlike jack mackerel, mesopelagic fish do not avoid fishing vessels, so their acoustic measurement is much more accurate. However, it is necessary to deepen the relationship between both species in order to be able to infer aspects of the jack mackerel ecology based on the study of one of its main prey.

Thus, during the SNP 2019 workshop a first approach was made to the relationship between the two species. In the report of that workshop, variograms were included that showed a very close spatial structure between jack mackerel and vinciguerria. A similar type of analysis has been carried out in the present (eighth) workshop, finding a similar or close relationship between both species using 2020 data. See figure 4.3.1.

In figure 4.3.1. also the geographical distribution of the acoustic values measured for jack mackerel and vinciguerria is observed, with an indication of their centers of gravity and inertia, which shows that in the summer of 2019 the Global Placement Index (GPI) had an overlap value of 0.77, which decreased to 0.45 during the summer of 2020. The figure shows the relative spatial proximity between both species, which suggests the need to study these aspects in depth.

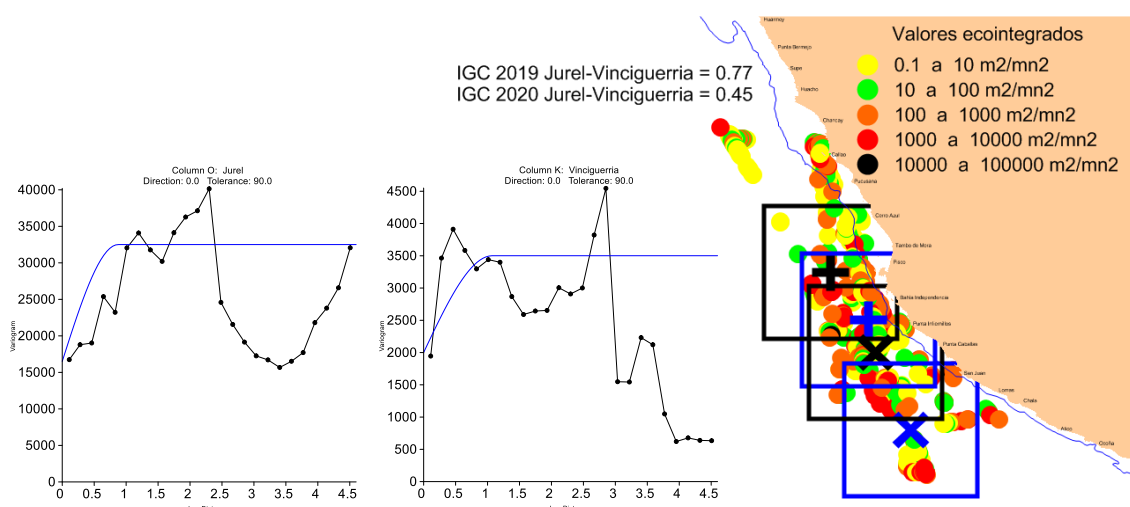


Figure 4.3.1. Variograms of the distribution of jack mackerel and vinciguerria for 2020 (left and central panels), and centers of gravity and inertia compared for jack mackerel and chub mackerel during summers 2019 and 2020 (right panel). The centers of gravity and inertia of jack mackerel are indicated by a blue cross or X, and those of vinciguerria are indicated in black.

## 5. Biological aspects of Jack mackerel, chub mackerel and other species

### 5.1. Jack mackerel size structure

The analysis of the size structure of jack mackerel was carried out with information obtained from biometric sampling made by the SNP's industrial fleet during 2018, 2019 and 2020. In 2018 a main mode was observed in 28 cm, in 2019 it changed to 34 cm, and in 2020 it was 38 cm. The percentage of juvenile jack mackerel registered in 2020 was lower than in 2018 and 2019. It should be noted that in 2020 there are records from January to March only (Figure 5.1.1.).

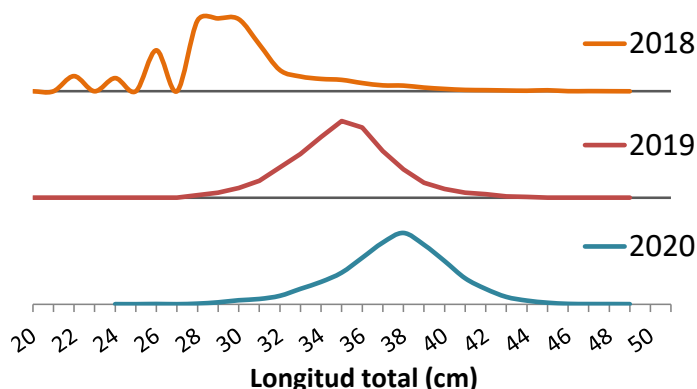


Figure 5.1.1. Jack mackerel size structure during 2018, 2019 and 2020 according to the biometric sampling carried out on board the SNP fleet.

From the analysis of jack mackerel lengths according to season, it is observed that in summer and spring of 2018 there was an entry into the fishery of modal groups of 22 and 28 cm (Figure 5.2.2.). The entry of these modal groups to the fishery represented the renewal of the jack mackerel stock for the following seasons.

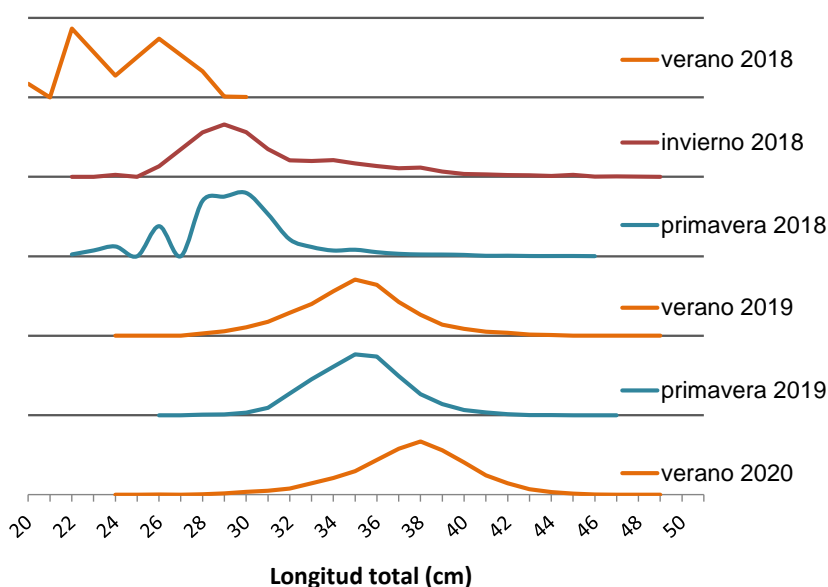


Figure 5.1.2. Jack mackerel size structure by season from 2018 to 2020 according to the biometric sampling carried out on board of the fishing fleet.

## 5.2. Chub mackerel size structure

Regarding the structure of chub mackerel, in 2018 a main mode was observed in 28 cm and a secondary mode of 26 cm, in 2019 there were two main modes of 32 and 33 cm and in 2020 the main mode was 30 cm with a 34 cm secondary mode (Figure 5.2.1.). The percentage of juvenile chub mackerel in 2020 was lower than during 2018, but higher than during 2019. It should be noted that in 2020 there are records from January to March only.

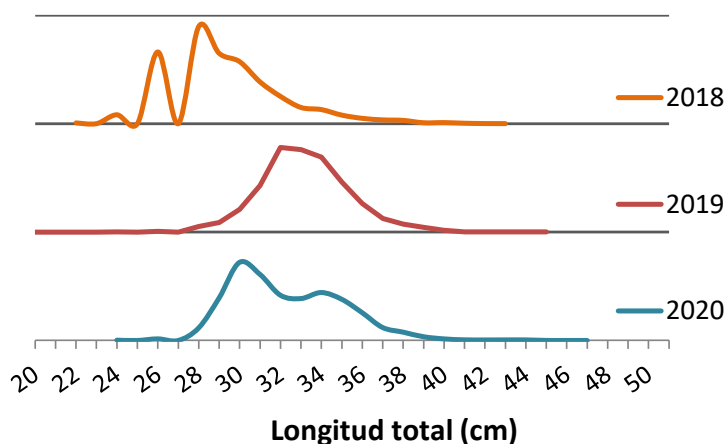


Figure 5.2.1. Chub mackerel size structure during 2018, 2019 and 2020 according to the biometric sampling carried out on board the SNP fleet.

From the analysis of length structure progression by seasons, it is observed in summer 2018 the entry into the fishery of a modal group of 26 and 28 cm (Figure 5.2.2.). There is certain consistence in the modal progression until Spring 2019. The size modes found during summer 2020 corresponds to a group not yet registered by the fishery.

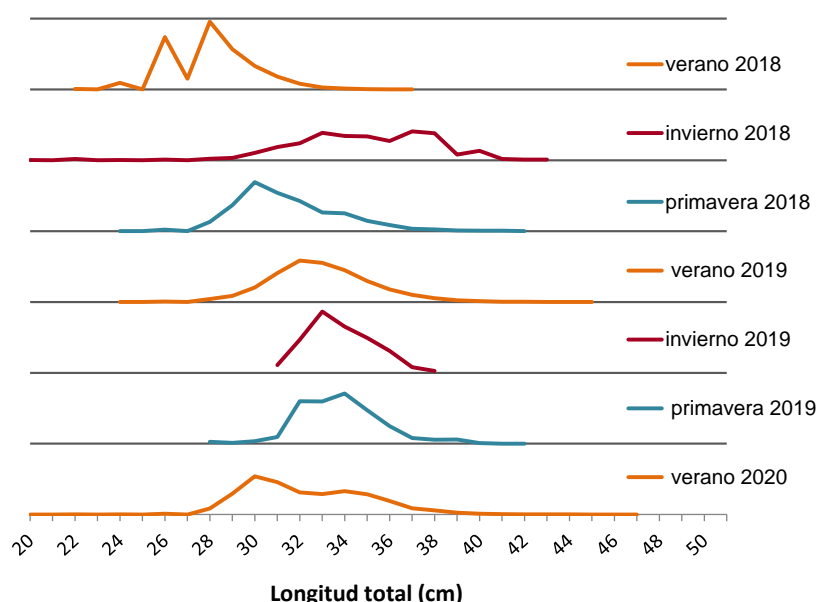


Figure 5.2.2. Chub mackerel size structure by seasons during 2018 to 2020 according to the biometric sampling carried out on board the fishing fleet.

### 5.3. Observation of the relationship of sea birds and sea mammal species (top predators) with Jack mackerel and chub mackerel during the summer 2002-03 Survey

Both jack mackerel and chub mackerel are part of the diet of some top predator species, particularly sea birds and mammals (Table 5.3.1.). During the 2002-03 IMARPE's Survey, there were numerous sightings of these predators (Figure 5.3.1.).

Table 5.3.1. List of predatory mammals of Jack mackerel and / or chub mackerel observed during Cr. 2002-

PARVORDEN	ESPECIE	NOMBRE COMÚN	PRESA	AUTOR, AÑO
ODONTOCETI	<i>Delphinus capensis</i>	Delfín común de hocico largo	Jurel Anchoveta, jurel, caballa	Reyes 2009 García-Godos et al. 2004
	<i>Delphinus delphis</i>	Delfín común de hocico corto	Peces mesopelágicos Pequeños escómbridos	Reyes 2009 Perrin 2018
	<i>Delphinus sp.</i>	Delfín común	Sin Información	
	<i>Lagenorhynchus obscurus</i>	Delfín oscuro	Jurel, anchoveta Anchoveta	Reyes 2009 Van Waerebeek y Würsig 2018
	<i>Tursiops truncatus</i>	Delfín nariz de botella	Anchoveta, jurel, caballa Anchoveta, jurel	García-Godos et al. 2004 Reyes 2009
	<i>Physeter macrocephalus</i>	Cachalote	Cefalópodos (pota: <i>Dosidicus gigas</i> , calamares)	Reyes 2009
CARNIVORA	<i>Arctocephalus australis</i>	Lobo fino	Anchoveta, caballa Anchoveta, jurel	Zavalaga et al. 1998 Arias - Schreiber 2000
	<i>Otaria flavescens</i>	Lobo chusco	Anchoveta, jurel Jurel, caballa	Zavalaga et al. 1998 Arias - Schreiber 2000

03.

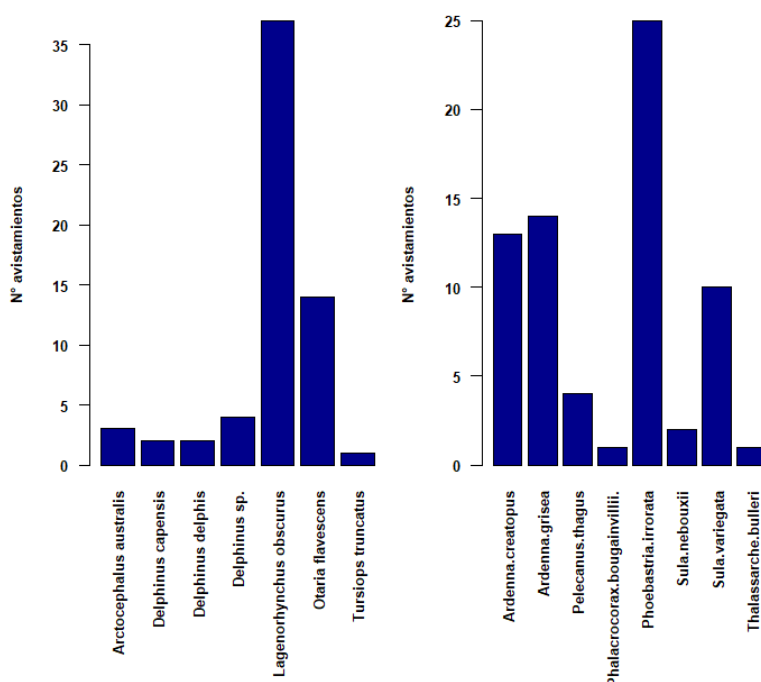


Figure 5.3.1. Number of sightings of sea mammals (left) and sea birds (right) during IMARPE's Survey 2002-03 that have jack and/or chub mackerel as components of their diet.

#### 5.4. Acoustic observations of the descriptors of the schools of jack mackerel and chub mackerel

An attempt was made to investigate whether the presence of top predators was influenced by the abundance of jack mackerel and / or chub mackerel. Therefore, a distribution map of the Nautical Acoustic Scattering Coefficient (NASC) of both fish was generated to overlap the sea bird and mammal sightings. Then they were scrutinized areas where interactions could have occurred.

These areas were defined using two criteria: on one side, if there is an agglomeration of predators, and on the other side, that the distance between an agglomeration and the location of a NASC positive interval (with presence of jack or chub mackerel) is less than or equal to 5 nautical miles. Two zones were found that met these criteria, both located in the central zone (Figure 5.4.1.). The zone near the coast (zone 1) was in the surroundings of Punta Bermejo-Supe, while the other zone (zone 2) was located near the continental slope, in the latitude of Casma-Huarmey. The top predators found in zone 1 were exclusively sea mammals; those of zone 2, exclusively sea birds. There was only chub mackerel in both areas, and their abundances were negligible compared to what was observed against, for instance, Salaverry, Huacho or Punta Caballas. These results suggest that, at least during the 2002-03 Survey, the top predator distribution was not influenced by jack or chub mackerel. In this sense, it is likely that the local abundance of anchovy is instead decisive to explain the top predators' distributions.

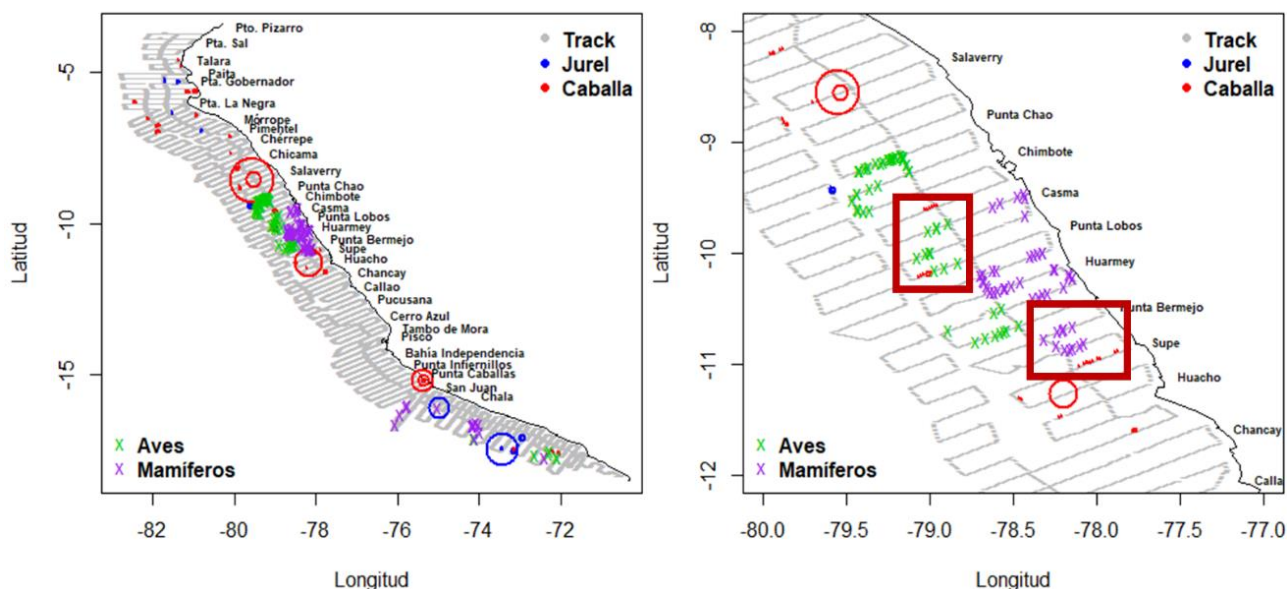


Figure 5.4.1. Distribution of NASC values for jack and chub mackerel, and top predator sightings during Survey 2002-03 (left) and areas of possible interaction between jack mackerel and chub mackerel with top predators (right).

To investigate on the relationship between the several studies variables, a principal component analysis (PCA) was performed. Taking into account the correlation between the variables that produced the morphological indices, it was decided the only those indices were used for the analysis. In Figure 5.4.2. the correlation of the variables in three components is observed. The first component is highly correlated with the energy descriptors (Sv\_mean, VerRoug and HorRoug). The second component is correlated with the morphometric indices of the schools (Elon, Cir and IC). Finally, the third component gives us information about the depth of the shoals (Depth).

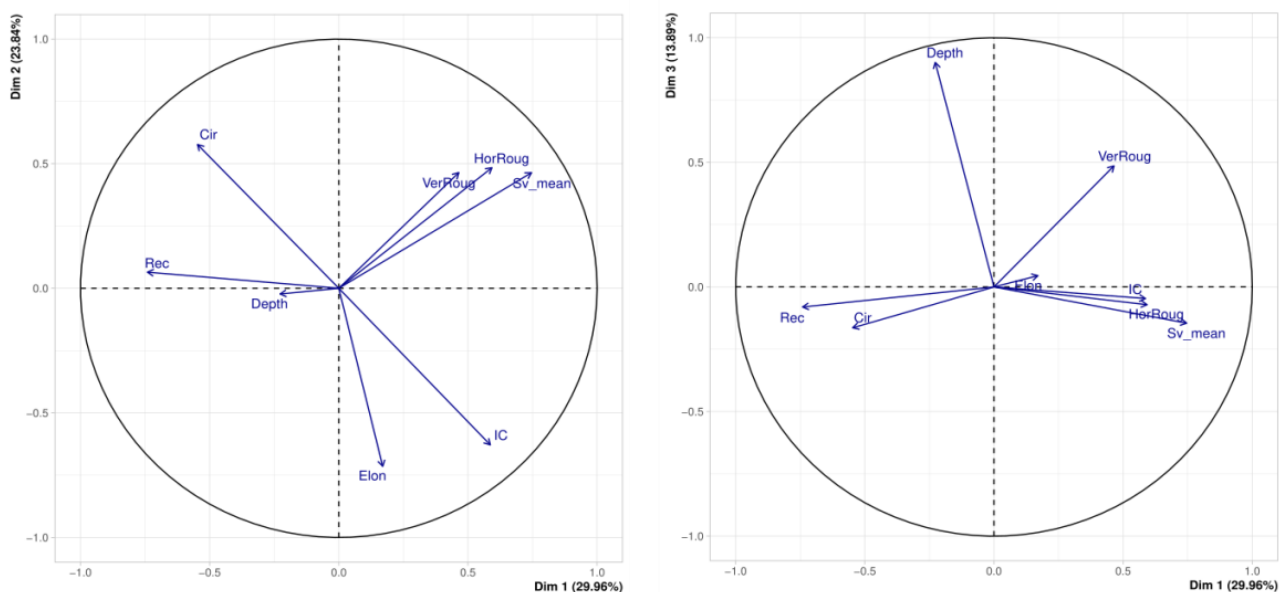


Figure 5.4.2. Variables projected in the space of the principal components. On the left are the 1 and 2 component projections, and on the right the 1 and 3 component projections.

Based on the results of the PCA analysis, the jack mackerel shoals were classified into three groups or clusters (Figure 5.4.3.). The densest clusters (higher energy values) have been found in the southern zone. The first cluster groups 50% of the jack mackerel shoals, being their metrics for height and length lower than the other two groups. Also, the denser fish shoals had a certain oval shape (high values of circularity compared to the other groups).

The second cluster groups 18% of the schools. They present the highest energy values, with an irregular shape (low circularity and elongation values). The third cluster groups 33% of the schools. These were the longest shoals (values for length and elongation were high compared to the other groups). Also, the depths of these shoals are variable, ranging from the surface to 20 m deep.

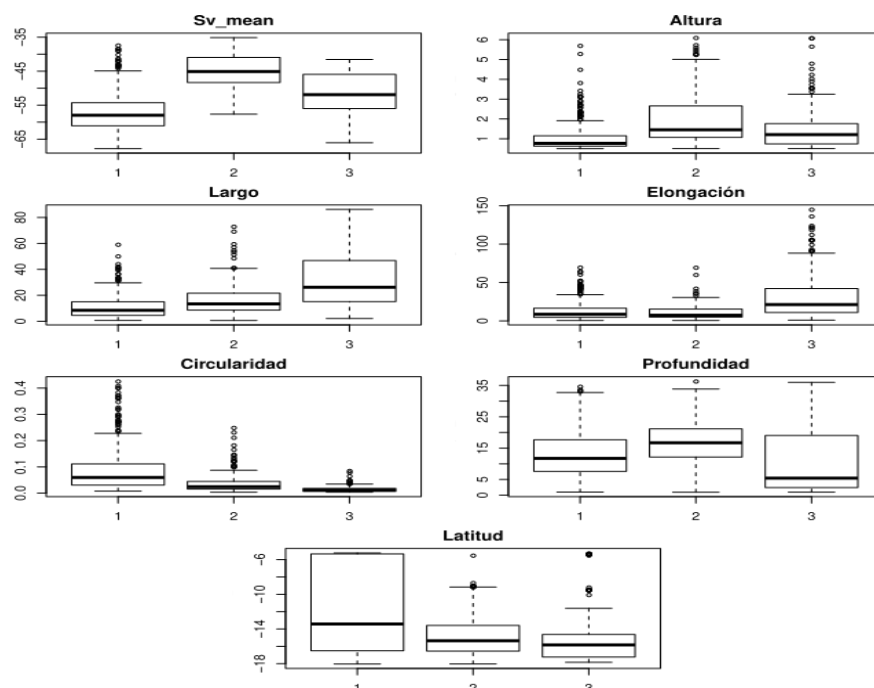


Figure 5.4.3. Boxplots corresponding to the acoustic descriptors of jack mackerel schools for each of 3 clusters. For each cluster number (x-axis) boxplots of the variables (y-axis) are presented. At the top of each graph is the name of the variable.

## 6. Conclusions

- During summer 2020 the presence of jack mackerel and chub mackerel has occurred concurrently in oceanic waters with relatively high temperatures, in Surface Subtropical Waters, which is unusual at least for the season.
- From the analysis of various analyzed variables regarding the habitat of jack mackerel and chub mackerel it is concluded that there is no single pattern for each season, at least for summer, which is the most important fishing season of the year. In other words, significant differences have been found between the summer months of 2018, 2019 and 2020.
- At least for 2019 and 2020, chlorophyll was not significant to explain the distribution of jack mackerel, since it is always observed in areas with low concentration values.
- During summer 2020 the distribution of jack mackerel was vertically limited (compared to summer 2019), and therefore more aggregated and available to fishing.
- The distribution of jack mackerel and *vinciguerria* presented a similar spatial structure (variogram) for summers 2018, 2019 and 2020, which could offer a key aspect to study regarding the jack mackerel habitat.
- During summer 2018 a modal group of 28 cm (total length) entered the fishery. This groups were again observed by the fleet in 2019 and 2020.
- It has been observed a modal progression of the caught chub mackerel during 2018 to 2019. However, during summer 2020 that modal group was not observed. Instead the entry of a different modal group of 30 cm was observed.

## 7. Recommendations

- Carry out more detailed acoustic analysis of the spatial relationship between jack mackerel and *vinciguerria*, taking advantage of the information collected by the fishing vessels participating in the IMARPE acoustic surveys carried out between years 2017 to 2020. It is also recommended to relate the abundance of both species depending on the local abundance of euphausiids. Due to the nictimeral cycle of meso-pelagic species, it is also suggested that the analyzes be carried out at the level of ecotraces (shoals), not fixed intervals.
- Carry out retrospective analysis of the relationship of jack mackerel and chub mackerel in relation to water masses. At least in the case of the acoustic detections carried out during the summer of 2020, it has been found that jack mackerel has shown preference for Surface Subtropical Waters (SSW).
- Establish protocols for collecting information aboard fishing vessels in coordination with IMARPE regarding biometric aspects. It must be ensured that the number of fishing sets with biometrics must be equal to the total number of sets registered by the fleet. Likewise, it is recommended to design protocols for biological aspects such as stomachs collections, and the registering on top predators interactions with the fleet.
- Due to the fact that during summer the sea lions are in their reproductive season and do not usually move away from the coast and/or islands, -which generates a bias in the sightings of these mammals- it is suggested to carry out the analysis on top predators using the winter-spring surveys, also with support of observers aboard fishing vessels.
- Implement a plankton sampling system, mainly ichthyoplankton, using biological nets on board fishing vessels to complement IMARPE analyzes.
- Promote the use of sonars to better understand the horizontal and vertical distribution behavior of jack mackerel and chub mackerel.

## 8. References

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