SPRFMO
South Pacific Regional Fisheries Management Organisation

9th MEETING OF THE SCIENTIFIC COMMITTEE

Held virtually, 27 September to 2 October 2021

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Habitat Conditions for Jack and Chub mackerel in the Peruvian Sea January 2020 to June 2021

Peru

Sociedad Nacional de Pesquería

INSTITUTO HUMBOLDT
INVESTIGACIÓN MARINA Y ACUÍCOLA

South Pacific Regional Fisheries Management Organisation
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Habitat conditions for Jack mackerel (*Trachurus murphyi*) and Chub mackerel (*Scomber japonicus*) in the Peruvian Sea between January 2020 and June 2021

by

SCIENTIFIC RESEARCH COMMETEE - SNP

This report contains information on the Jack mackerel and chub mackerel fish stocks and fisheries in Peruvian jurisdictional waters that, we reiterate, the delegation of Peru, in use of its discretionary powers, voluntarily provides for the purpose of information and support to the scientific research work within the Scientific Committee of the SPRFMO. In doing so, while referring to Article 5 of the Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean and reiterating that Peru has not given the express consent contemplated in Article 20 (4) (a) (iii) of the Convention, Peru reaffirms that the decisions and conservation and management measures adopted by the SPRFMO Commission are not applicable within Peruvian jurisdictional waters.

LIMA, PERU, AUGUST 2021

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by

SCIENTIFIC RESEARCH COMMETEE - SNP

INDEX

LIMA, PERU

Summary

An updated analysis of changes in Jack mackerel and Chub mackerel habitat occurring during 2020 and the first half of 2021 has been carried out based on information from fishing sets and areas of operation of the SNP fishing fleet. The pandemic restrictions have prevented the collection of information on additional species, such as mesopelagic fish and top predators.

It was observed that during summer 2021 the presence of Jack mackerel and Chub mackerel has again been typical, *i.e.*, along the fronts between oceanic and coastal water masses, whereas in 2020 they were observed in oceanic water masses, which was considered unusual.

From the analysis of the various variables analyzed with respect to the habitat of Jack mackerel and Chub mackerel, it is concluded that in 2020 and 2021 the conditions have been different from those of previous years, where the only parameter analyzed that remained similar is salinity. Another noticeable observation is that both species have been available to the fishing fleet in areas with low chlorophyll concentration and relatively high values of sea surface altimetry and its anomalies. In the case of Jack mackerel, its distribution was important in the south, and less abundant in the north. On the other hand, in the case of Chub mackerel, a wider latitudinal availability was observed.

In recent years there has been a positive trend with respect to Jack mackerel availability, i.e., an increase towards average levels of abundance. The catches in the period 1983-2021 also show, in general, better yields in years when the biomass has been higher. The highest abundance of Jack mackerel, through geostatistical methods, was estimated during September 2020, with 855 thousand tons, followed by March 2021 with 518 thousand tons. Vertically, Jack mackerel had a shallower distribution during summer 2021 than what it was observed during summer 2020. Likewise, Jack mackerel was more aggregated and available to fishing during summer 2021.

Also, in recent years there has been a positive trend in Chub mackerel availability, i.e., an increase towards average levels of abundance. Catches over the same period (1983-2021) also show, in general, better yields in years when biomass has been higher. The highest abundance of Chub mackerel, through geostatistical methods, was estimated during February 2020, with 247 thousand tons, followed by September 2020 with 236 thousand tons.

Regarding the size structure of Jack mackerel, a modal group of 28 cm in total length was observed entering the fishery during summer 2018, which was again observed by the fishing fleet between 2019 and 2021. From the size distribution of Chub mackerel, it was observed during the last two years the recruitment of new age groups, particularly between 7°S and 8°S.

In the SNP workshop reports submitted in 2019 and 2020 to the SPRFMO Habitat Monitoring Working Group, as well as in the present case, it is specified that the focus of the reports has been the mapping and modeling of the ideal environmental conditions (habitat) for fishing adult Jack mackerels in the short term, i.e. environmental parameters have been related to the presence and relative abundance of acoustically detected schools, as well as the catches obtained by the industrial fishing fleet. However, this report has also included information collected by the Peruvian Marine Research Institute (IMARPE) in areas that do not correspond to the fishing zones of the industrial fleet. It is a pending task the modeling of the ideal environmental conditions for the renewal and growth of the local population, for example, relating environmental parameters to the success of the reproductive process and recruitment, including possible changes and effects on critical mortality in the larval and post-larval phases.

1. Introduction

The Scientific Research Committee (CIC) of the National Fisheries Society (SNP), in cooperation with the Humboldt Institute for Marine and Aquaculture Research (IHMA) organized the **Nineth SNP Workshop on habitat conditions of Jack mackerel and other species of the Peruvian Current in the Humboldt System**, which was held virtually from June 21 to 25, 2021. As usual, there was a valuable participation and contribution of researchers from the Peruvian Marine Research Institute (IMARPE). This activity is a contribution to the national and international effort to investigate and diagnose the current population status of various species, with emphasis on Jack mackerel and aspects related to their habitats, and is an activity that has been developed since the first workshop in 2011. The list of scientists who have participated in the drafting of this document is included in Annex 1.

1.1. On the difference between the concepts of biomass and abundance

This report among other concepts refers to "acoustic abundance" and "geostatistical abundance". These expressions are related to the quantity of fish that has been calculated only in the areas of operation of the fleet. It is emphasized that these definitions do not refer to the total biomass of fish in the Peruvian water masses, since the operations of the fleet only cover a variable fraction of the probable total distribution of Jack mackerel and other species of interest in this area. Likewise, it is pertinent to bear in mind that the Peruvian Jack mackerel (*T. murphyi*) fleet also has authorization to fish for Chub mackerel (*S. japonicus*), and that generally only operates in the Jack mackerel and Chub mackerel fisheries during summer and early fall, since the same fleet also fishes for anchoveta (*E. ringens*), and does not target on other species during the anchoveta fishing season. The anchoveta fishing seasons are usually set between early fall and early summer of the following year. In other words, Jack and Chub mackerel are a combined fishery whose operations are conditioned by the anchovy fishing seasons.

This document presents a synthesis of the environmental conditions observed in the Peruvian water masses from January 2020 to June2021 where the variability of oceanic conditions is related to the availability of Jack mackerel and Chub mackerel. The fishery data has been provided by fishing companies associated to National Fisheries Society (SNP) operating in the Peruvian jurisdiction in the northern region of the Peru Current System. The Table 1.1 presents a summary of the main oceanographic and distribution parameters and abundance of Jack mackerel and Chub mackerel between 2011 and 2020. Regarding catches, the data included is only related to the fleet of the fishing companies associated to SNP.

Table 1.1. Synthesis of catches and abundance of Jack mackerel and Chub mackerel, as well as prevailing environmental conditions observed between January 2011 and June 2021.

Parameters / Years	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Sea Surface Temperature (SST, ° C)	Cold	Normal	Cold	Normal	Warm	Warm	Warm	Cold	Normal	Normal	Normal
TSM anomalies (ATSM, ° C)	Cold	Normal	Cold	Normal	Warm	Warm	Warm	Cold	Normal	Normal	Normal
Salinity (UPS)	High	Low	High	Normal	Low	Low	Low	High	Normal	High	Normal
Sea Surface Anomaly (SLA)	Normal	Normal	Normal	Normal	High	High	High	Normal	Normal	Normal	Low
El Niño	-	-	-	-	Moderate	Weak	Moderate	-	-	-	
La Niña	Strong	-	-	-	-	Moderate	Moderate	Weak	-	-	Weak
Jack mackerel overall distribution	North	South Central	South Central	South Central	South Central	South Central	South Central	North-Center	South Central	South Central	South Central
Chub mackerel overall distribution	North	Central	-	Central	Central	Central	Central	Central	Central	South Central	Central
Fishing sets Jack mackerel	2,971	1,944	1,207	1,675	-	-	-	733	861	1,004	453
Fishing sets Chub mackerel	215	39	-	107	26	790	782	319	85	1,016	472
Jack mackerel catches	208,000	113,000	28,000	45,000	20,000	13,500	10,505	37,106	86,981	76,000	53,000
Chub Mackerel catches	42,000	7,000	30,000	28,000	35,000	140,000	89,428	30,821	39,916	60,290	37,000
Jack mackerel abundance (ton., Geostatistics)	639,000	158,000	70,000	163,000	-	-	-	91,166	511,813	855,000	518,000
Jack mackerel abundance (ton., Acoustic)	788,764	476,947	87,000	332,000	-	-	-	-	250,000	200,000	-
Chub Mackerel abundance (ton., Geostat.)	86,140	9,787	-	219,746	15,211	864,359	782,514	23,254	403,858	247,000	236,000
Chub Mackerel abundance (ton, acoustic)	-	-	-	-	-	-	-	-	-	-	816,836
Jack Mackerel mode (cm)	32	33	33 y 43	33	25	24	24 y 29	28	26 y 34	38	44
Chub Mackerel mode (cm)	29	31	32	32	29	27	29	26	15 y 33	28	35
Size ranges for jack mackerel (cm)	26-34	27-36	23-48	24-43	22-28	24-26	15-46	21-46	28-45	26-52	28 - 52
Size ranges for Chub mackerel (cm)	28-30	25-37	20-36	24-40	24-37	20-34	20-36	22-37	27-40	25-38	24 - 42

2. Description of the habitat of Jack mackerel and Chub mackerel using satellite oceanographic and fishery information sources

Various oceanographic parameters are presented for the summers of 2019, 2020 and 2021 with an indication of the Jack mackerel and Chub mackerel fishing sets (represented by symbols), as these were the most favorable months for fishing. Figures 2.1.1 to 2.1.5. show, from left to right, the oceanographic parameters for January 15, February 15, and March 15 of each year, taken as proxies of summer seasons, in order to show the changes that have occurred in the last three years and their relationship with the relative availability of adult Jack mackerel and Chub mackerel.

2.1. Sea surface temperature (TSM, °C) between summers of 2019 to 2021

During the described period, the presence of Jack mackerel and Chub mackerel has been observed along thermal fronts, with the exception of February and March 2020, when the presence of both species occurred in oceanic water masses (subtropical surface water masses). Likewise, Jack mackerel fishing sets were conducted outside the continental shelf. It is considered that, in general, the moderate thermal conditions of the last three years have led to a denser aggregation of Jack mackerel, especially in the southern zone. Chub mackerel, on the other hand, has tended to be distributed -as usual- towards the north, as the presence of shallow equatorial water masses has been predominant in that area during recent summers (Figure 2.1.1).

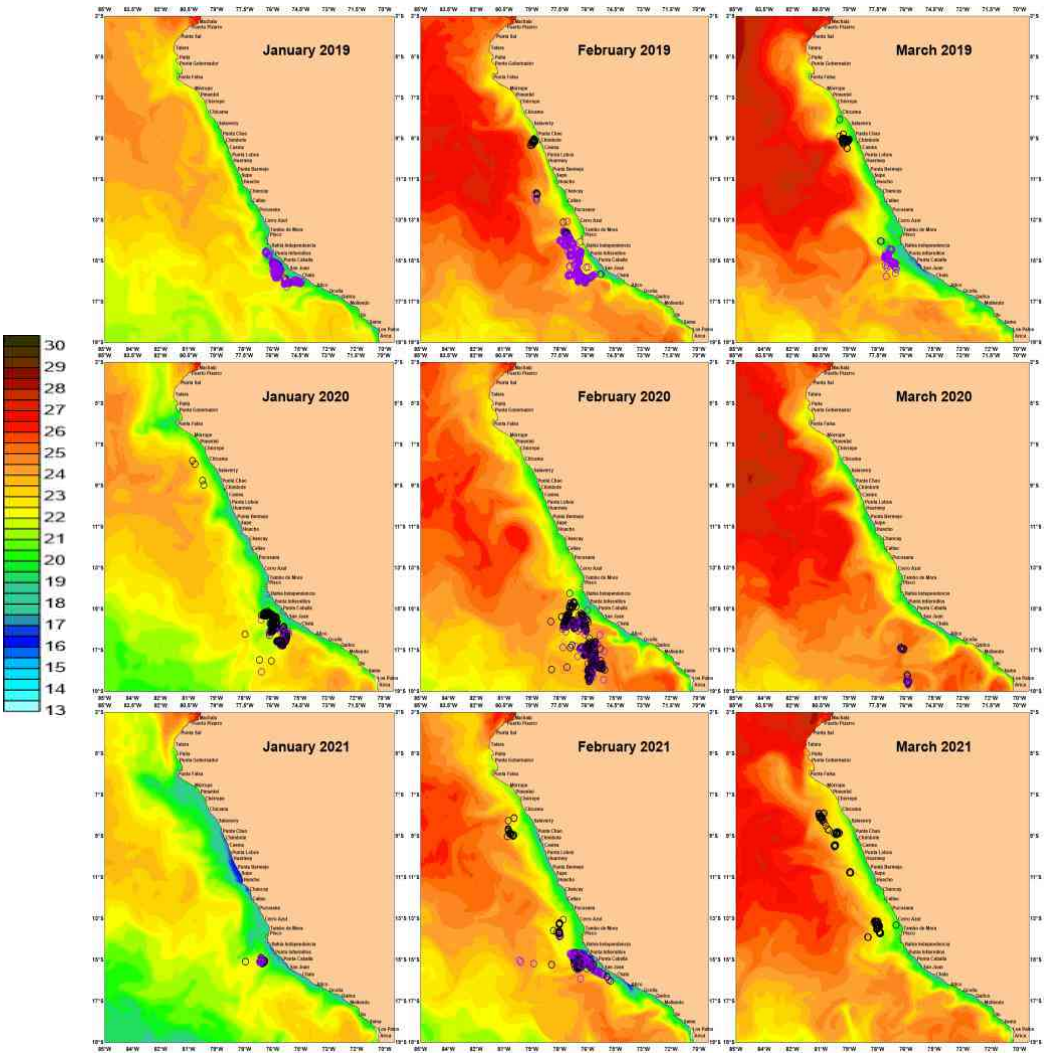

Figure 2.1.1. Mean sea surface temperature (TSM, °C) during 15th of January (left column), 15th of February (central column) and 15th of March (right column) of years 2019 (upper panel), 2020 (central panel) and 2021 (lower panel) to represent summer conditions during those years. Jack and Chub mackerel fishing sets made each month are indicated by black circles, and the Chub mackerel fishing sets are indicated by purple circles.

2.2. Sea surface temperature anomaly (ATSM, °C) between summers from 2019 to 2021

Summer 2019 was characterized by frequent changes in sea surface temperature anomaly (ATSM, in °C) values, especially along the southern coast, yet Jack mackerel fishing areas remained geographically unchanged in the central-south zone. The year 2020 had a summer characterized by negative thermal anomalies along the entire coast. It is under these conditions that the denser aggregation of Jack mackerel and Chub mackerel occurred - instead - over areas with positive thermal anomalies in the southern zone. In 2021 there were higher negative anomalies than in 2020, but only during January and February. In these conditions, Jack mackerel fishing areas were distributed, as in 2019, in the area located south of the Paracas Peninsula. Chub mackerel instead had some areas of distribution in the north and center, but also areas where it overlapped with Jack mackerel in the south (Figure 2.2.1).

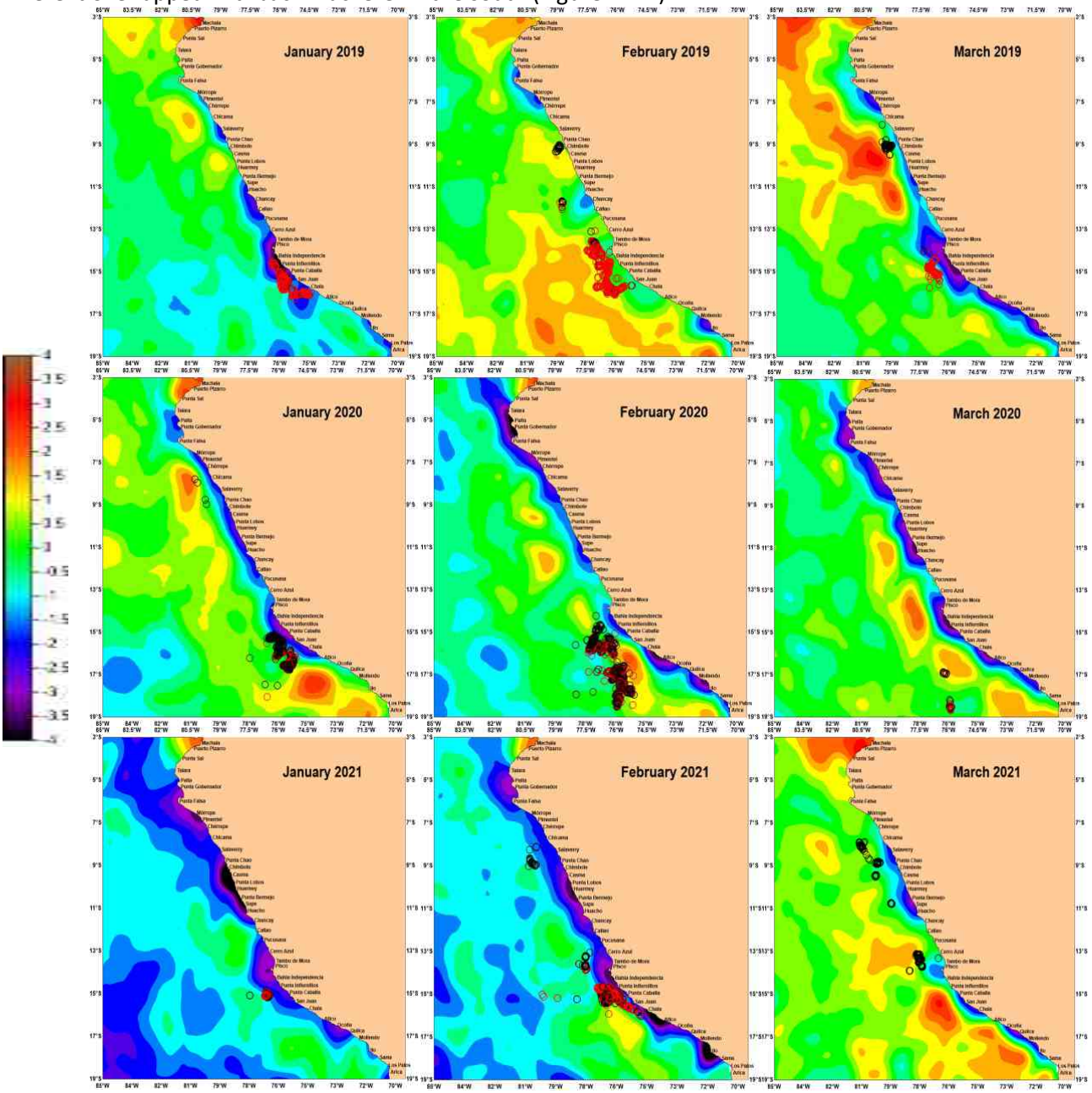

Figure 2.2.1. Mean anomalies of sea surface temperature (ATSM, °C) during 15th of January (left column), 15th of February (central column) and 15th of March (right column) of years 2019 (upper panel), 2020 (central panel) and 2021 (lower panel) to represent summer conditions during those years. Jack and Chub mackerel fishing sets made each month are indicated by black circles, and the Chub mackerel fishing sets are indicated by purple circles.

2.3. Sea surface salinity (ups) between years 2019 to 2021

During the summer of 2019, the presence of Jack mackerel and Chub mackerel was observed in areas of mixed waters between subtropical surface water masses (ASS) and cold coastal water Masses (ACF), mainly in the central and southern areas. In that year, the predominance of Chub mackerel in the north and Jack mackerel in the south was also observed. During summer 2020, a predominance of ASS is observed in the south, which is where the highest concentrations of Jack mackerel and Chub mackerel were found, which could be explained by the presence of suitable conditions in that area I despite its warmer conditions. In 2021 the Chub mackerel fishing areas were distributed both in the center and in the south along the front between ACF and ASS; in the case of Jack mackerel, in 2021 its fishing areas have been located approximately in the same regions as in 2019, i.e., south of the Paracas Peninsula along the front between ACF and ASS (Figure 2.3.3).

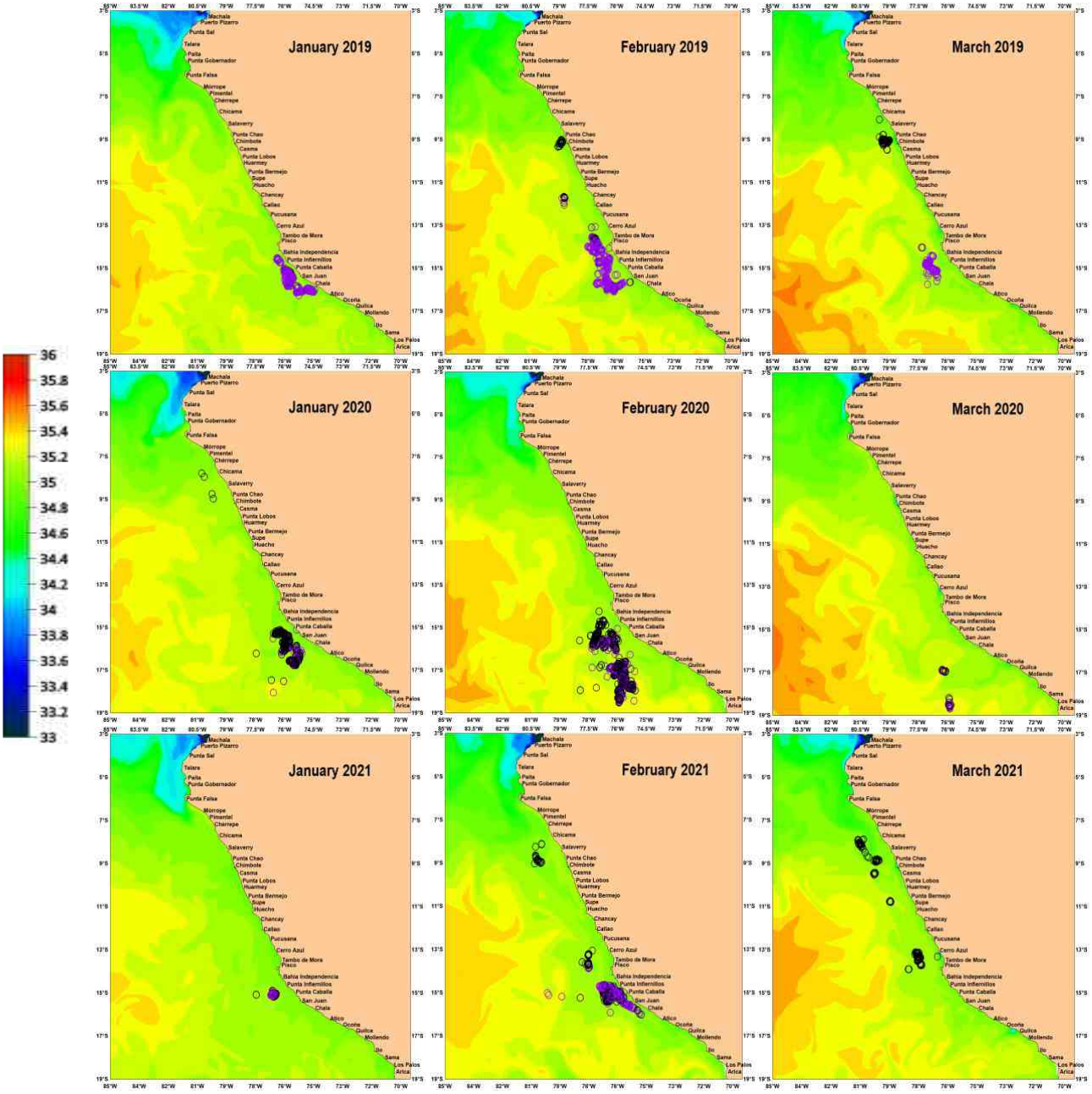

Figure 2.3.3 Mean Sea surface salinity (ups) during 15th of January (left column), 15th of February (central column) and 15th of March (right column) of years 2019 (upper panel), 2020 (central panel) and 2021 (lower panel) to represent summer conditions during those years. Jack and Chub mackerel fishing sets made each month are indicated by black circles, and the Chub mackerel fishing sets are indicated by purple circles.

2.4. Sea surface chlorophyll (ug/Lt) between years 2019 to 2021

During the summer of 2019, a lower than usual chlorophyll concentration was observed; on that conditions Jack mackerel and Chub mackerel were found over the outer edges of the higher chlorophyl concentration in the central and southern areas. The summer of 2020 was characterized by higher chlorophyll concentrations, but this time the preference of Jack mackerel and Chub mackerel was in oceanic water masses and not on the edges of the coastal upwelling. In 2021, the presence of both species is again observed on the outer edges of chlorophyll (Figure 2.4.1).

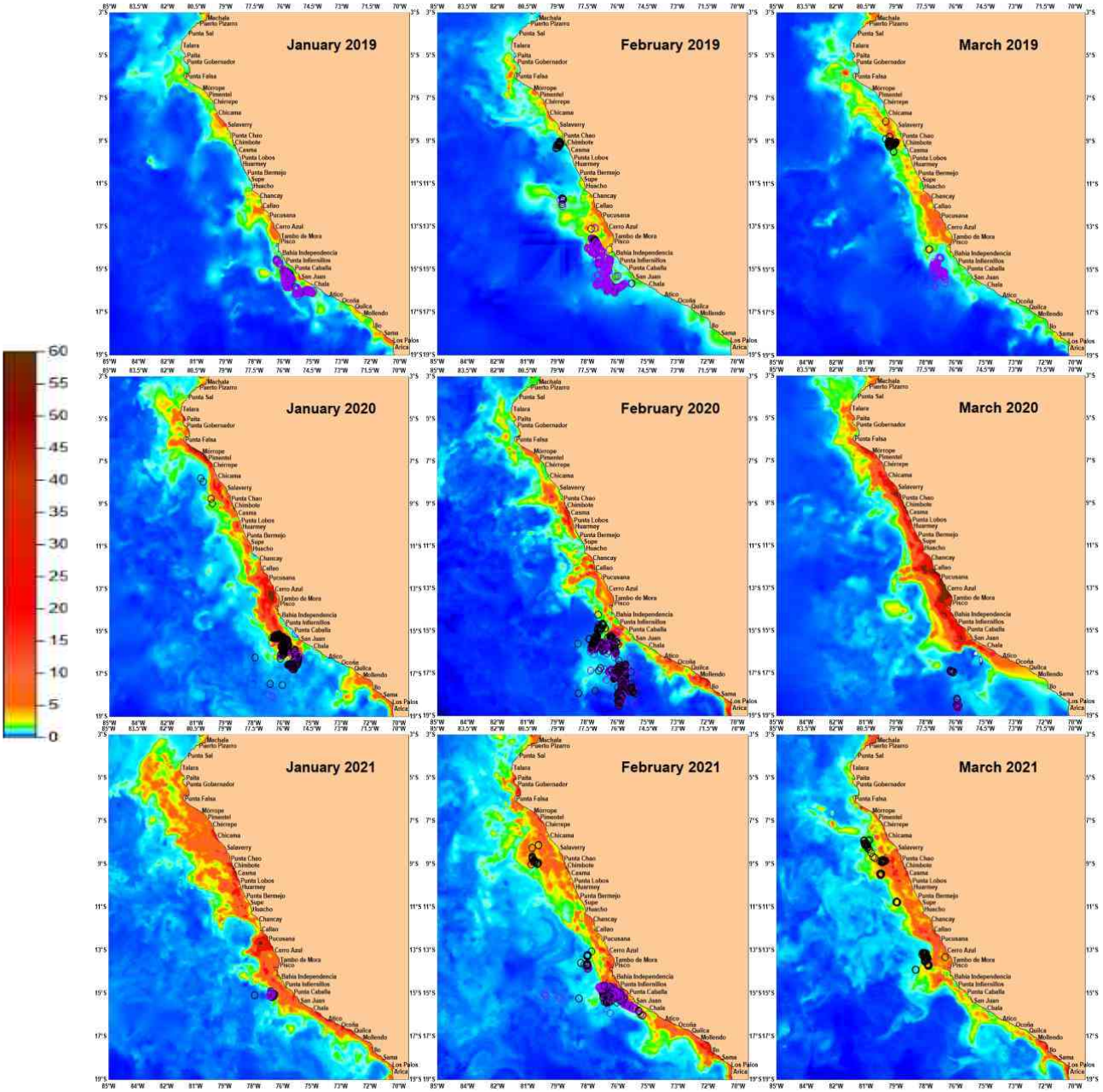

Figure 2.4.1. Mean Sea surface chlorophyll (mg/m^3) during 15th of January (left column), 15th of February (central column) and 15th of March (right column) of years 2019 (upper panel), 2020 (central panel) and 2021 (lower panel) to represent summer conditions during those years. Jack and Chub mackerel fishing sets made each month are indicated by black circles, and the Chub mackerel fishing sets are indicated by purple circles.

2.5. Sea Level Anomaly (SLA, cm) between years 2019 to 2021

During summer months of years 2019 to 2021 -except January 2021- it was observed a higher oceanic dynamic, which is associated with a denser availability of Jack mackerel and Chub mackerel, but mainly in the southern area. More specifically, the availability of adult Jack mackerel and Chub mackerel has been related to medium to high SLA values (Figure 2.5.1).

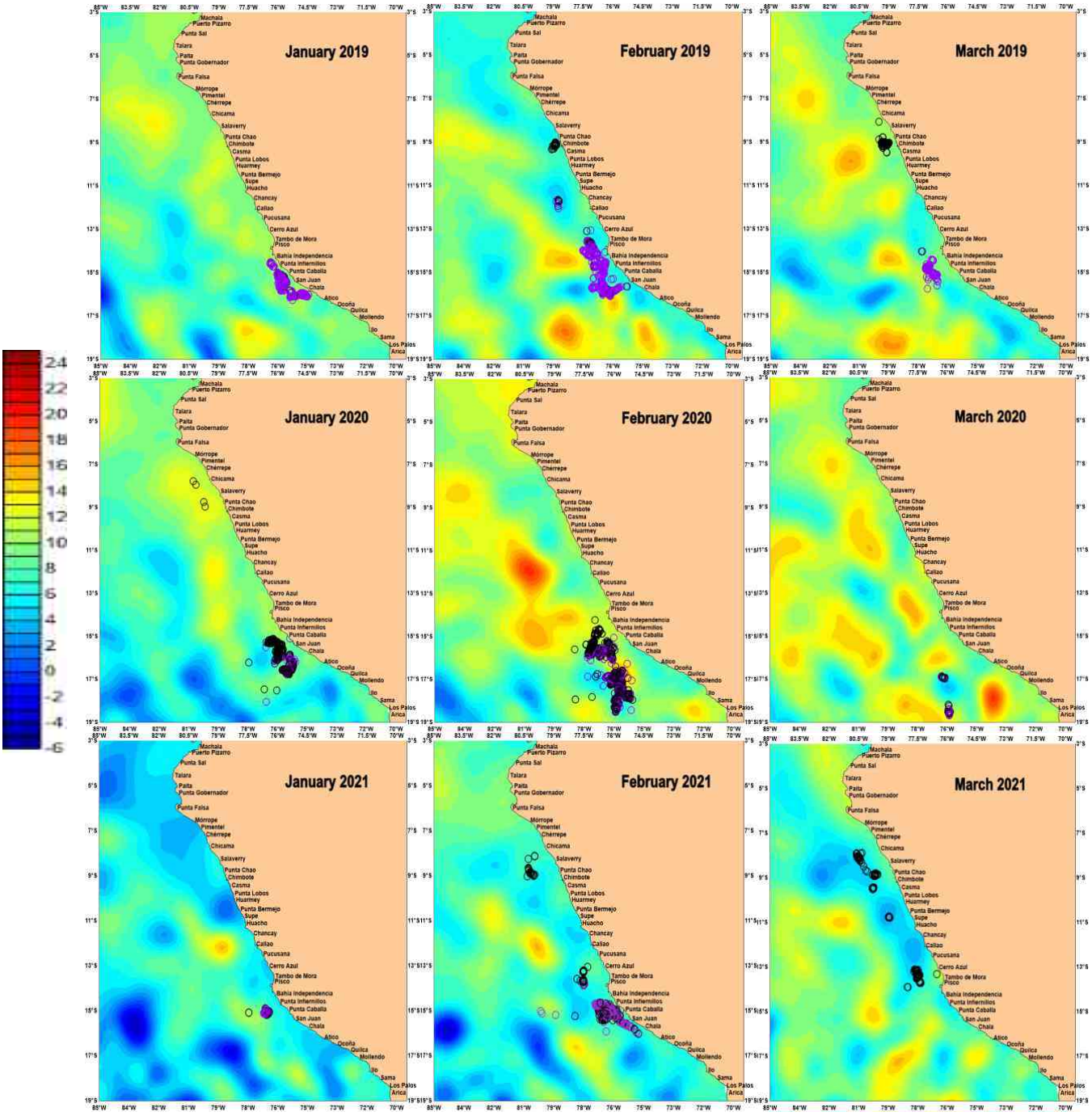

Figure 2.5.1. Mean Sea level anomaly (cm) during the 15th of January, February and March of the years 2019, 2020 and 2021, as representative of the summer season, and Jack mackerel and Chub mackerel fishing sets made during each of those months. Jack mackerel fishing sets are indicated by black circles, and Chub mackerel fishing sets are indicated by purple circles.

2.6. Analysis of variability of oceanic conditions related to availability of adult Jack mackerel and Chub mackerel during 2019, 2020 and 2021.

Figures 2.6.1 and 2.6.2 present the comparative results of the variability analysis of oceanic parameters relevant to the distribution and availability of adult Jack mackerel and Chub mackerel species in 2019, 2020 and 2021. The parameters analyzed, obtained from satellite sources were: sea surface temperature (TSM, °C), sea surface temperature anomaly (ATSM, °C), sea surface salinity (SALINIDAD, ups), Chlorophyll (ug/Lt), surface level anomaly (SLA, cm), sea surface altimetry (ALT, cm), latitude (LAT), distance from the coast (DC) and month of the year (MESES).

For Jack mackerel, Figure 2.6.1. shows notable differences between several parameters for years 2019 to 2021. For TSM, a wide range of thermal values (between 16 and 24°C) is appreciated, with a preference for relatively high temperatures during 2019, and for a wide thermal range during 2020 and with relatively low values during 2021. Unlike previous years, Jack mackerel distribution is related to a wide range of ATSM (between -4 to +2°C). In contrast, SALINIDAD remained in a discrete range of values (35.0 to 35.2 ups) and low values of chlorophyll concentration (< 3 ug/Lt). Regarding SLA and ALT, the presence of Jack mackerel is almost entirely confined to positive values, but not beyond values of 15 cm. Latitudinally, the distribution of Jack mackerel presented a restricted range in the analyzed years, although it should be specified that the present description represents only the areas of operation of the fleet, which has operated mainly in the southern zone between 2019 and 2021. Regarding its distribution according to its distance from the coast,

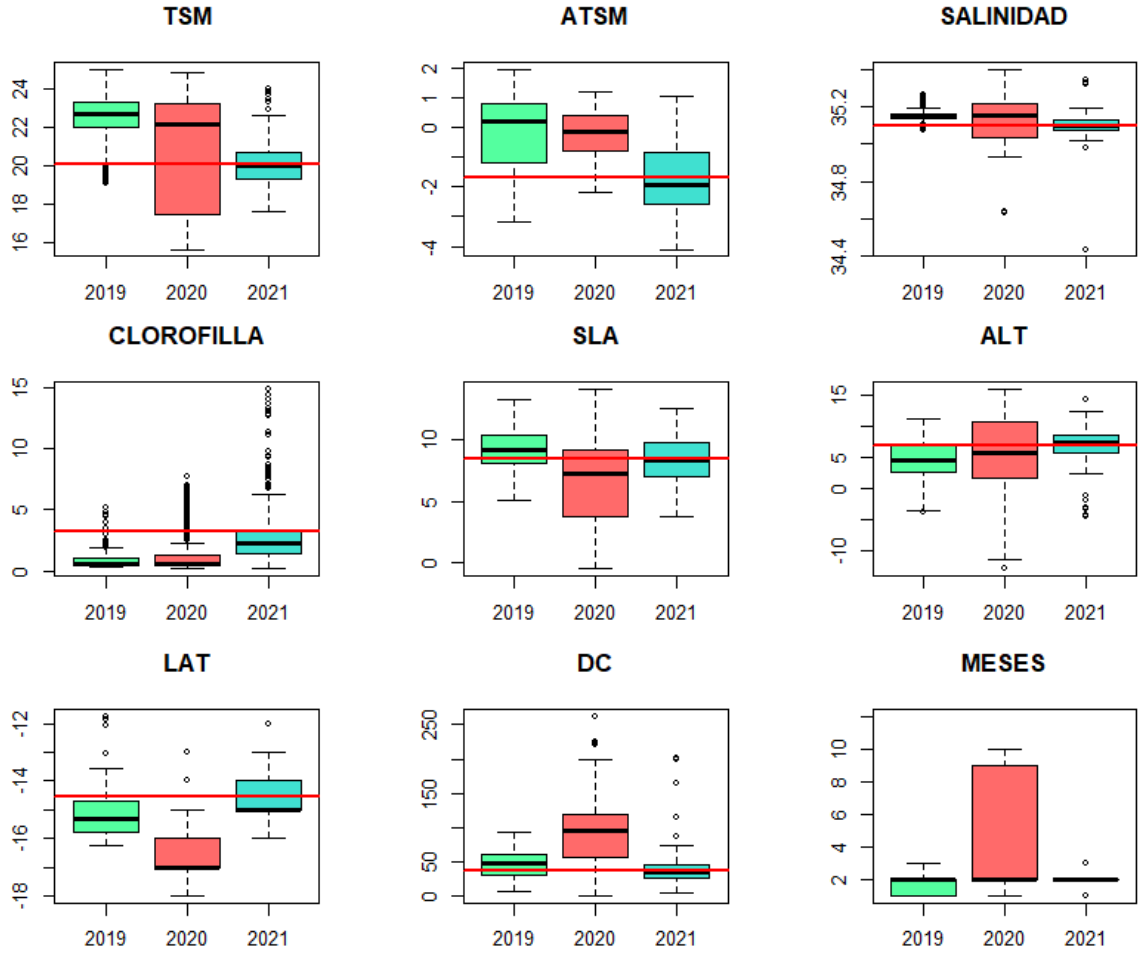

Figure 2.6.1. Boxplot analysis of variability of parameters for Jack mackerel from 2019 to 2021: sea surface temperature in °C (TSM), sea surface temperature anomaly (ATSM, °C), sea surface salinity in ups (SALINIDAD), chlorophyll (CLOROFILLA, mg/m3), surface level anomaly (SLA, cm), Altimetry (ALT, cm), latitude (LAT), distance off coast (DC, n.mi.) and months (MESES). The red line in each box indicates the average value of every measurement.

Jack mackerel was at relatively close distances during 2019 and 2021, but farther from the coast during 2020. Finally, the seasonality of the availability of Jack mackerel is directly related to national fisheries management, specifically according to the development of the anchoveta fishing seasons; thus, in 2020 there was a brief fishing season during September.

For Chub mackerel, Figure 2.6.2 shows, as for Jack mackerel, some differences, but also similarities between several parameters between years 2019 to 2021. For TSM, different ranges of thermal values (between 16 and 24°C) are appreciated, having been distributed in warmer conditions in 2019, and colder during 2021. Likewise, the distribution of Chub mackerel is related to a wide range of ATSM (between -4 to +2°C), but discrete in the case of SALINIDAD (34.7 to 35.4 ups), and with low chlorophyll values in the 3 analyzed years. As for SLA and ALT, the presence of Chub mackerel is almost entirely confined to positive values, but not beyond values of 15 cm. Latitudinally the distribution of Chub mackerel was wide during 2019, with a tendency to the south in 2020, and with denser availability in the central area during 2021. In terms of its distribution according to its distance from the coast, Chub mackerel was relatively close to the coast during 2019 and 2021, and away from the coast in 2020. Finally, the seasonality of the distribution of Chub mackerel, being the same fleet that fishes Jack mackerel, is directly related to national fisheries management, specifically according to the development of anchoveta fishing seasons; thus, the fishing season for these species is mainly developed during the summer, which is the period in which there is no fishing on anchoveta. However, during 2020 there was a brief fishing season during September.

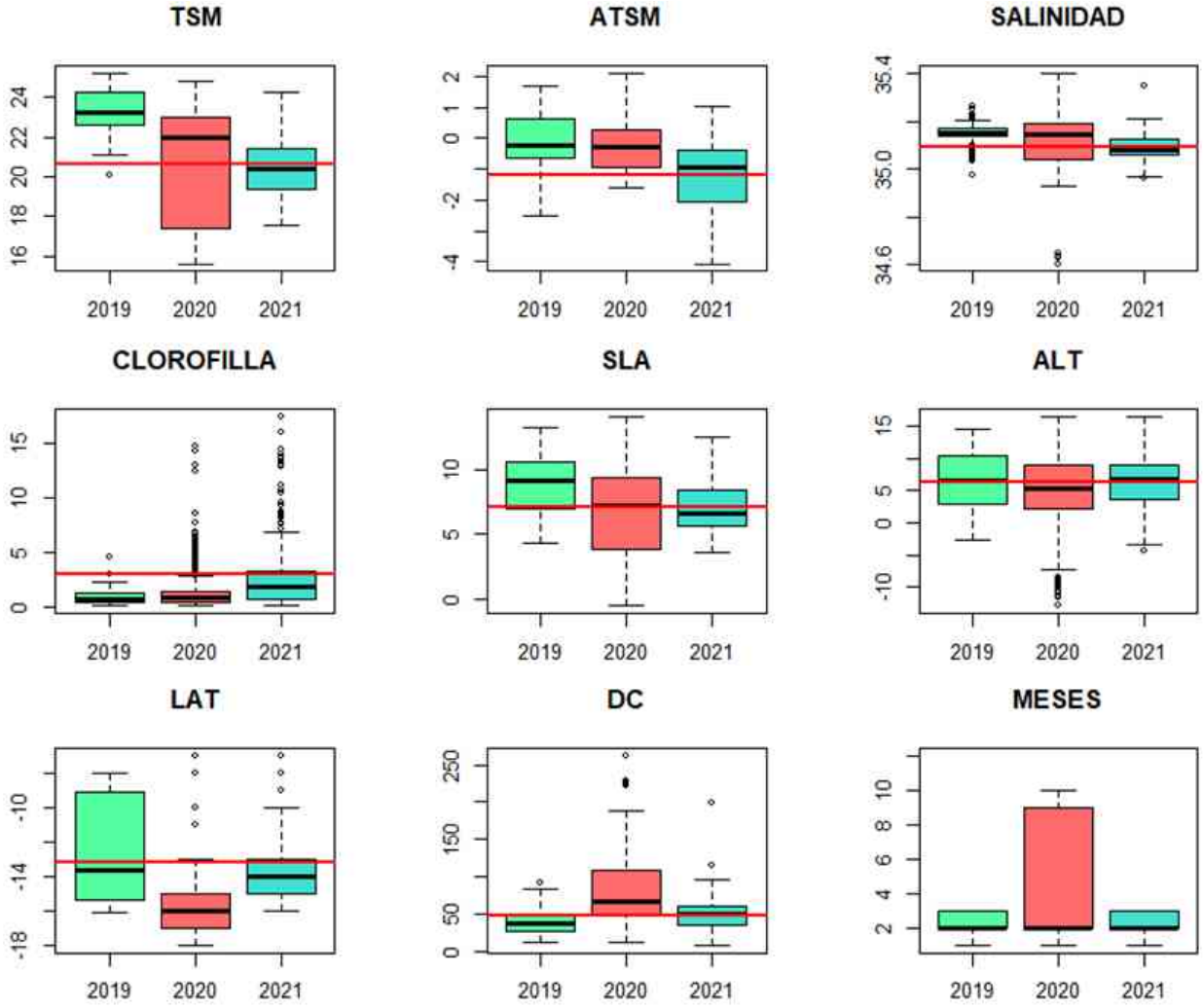

Figure 2.6.2. Boxplot analysis of variability of parameters for Chub mackerel from 2019 to 2021: sea surface temperature in °C (TSM), sea surface temperature anomaly (ATSM, °C), sea surface salinity in ups (SALINIDAD), chlorophyll (CLOROFILLA, mg/m3), surface level anomaly (SLA, cm), Altimetry (ALT, cm), latitude (LAT), distance off coast (DC, n.mi.) and months (MESES). The red line in each box indicates the average value of every measurement.

2.7. Vertical aggregation and mass indices of Jack mackerel

To describe the variability of Jack mackerel in the water column, vertical aggregation (IA) and center of mass (CM) indices were calculated according to Urmy et al. (2012). For this purpose, spatial gridding was performed in 60x60 minutes cells; within each cell the two indices were calculated. For this purpose, it was used the acoustic data of Jack mackerel shoals (fish schools acoustically detected) obtained by the fishing fleet and by IMARPE for the summers between years 2019 to 2021.

The IA refers to the vertical aggregation of schools within an area; this index will be high when the area presents higher densities compared to the rest of the distribution, while the CM indicates the central position of the fish schools in the water column.

Figure 2.7.1. shows the results of the vertical aggregation index (IA). It can be seen that for the summer of 2021 the fish was found to be more aggregated in the northern zone compared to the southern zone in despite the fact that the fleet did not operate in that area. These IA results are related to those obtained by the center of mass index (CM; Figure 2.7.2) where Jack mackerel is found shallower in the northern zone compared to the southern zone. Additionally, the northern zone has mainly detections made during February by IMARPE, while in the southern zone were analyzed detections made by the fishing fleet between January and March. The different vertical distribution of Jack mackerel in the southern zone responds to also different oceanic conditions, which expand or compress the Jack mackerel habitat. Furthermore, the detections of Jack mackerel made in the north area corresponded mostly to juvenile fish.

In conclusion, compared to the summers of 2019 and 2020, in summer 2021 Jack mackerel schools were mainly aggregated in the north, where denser aggregations were present (IA > 0.1). Likewise, in summer 2021 Jack mackerel schools were found to be shallowly distributed in the northern area compared to summer 2020 where the shallowest schools were detected in the southern area.

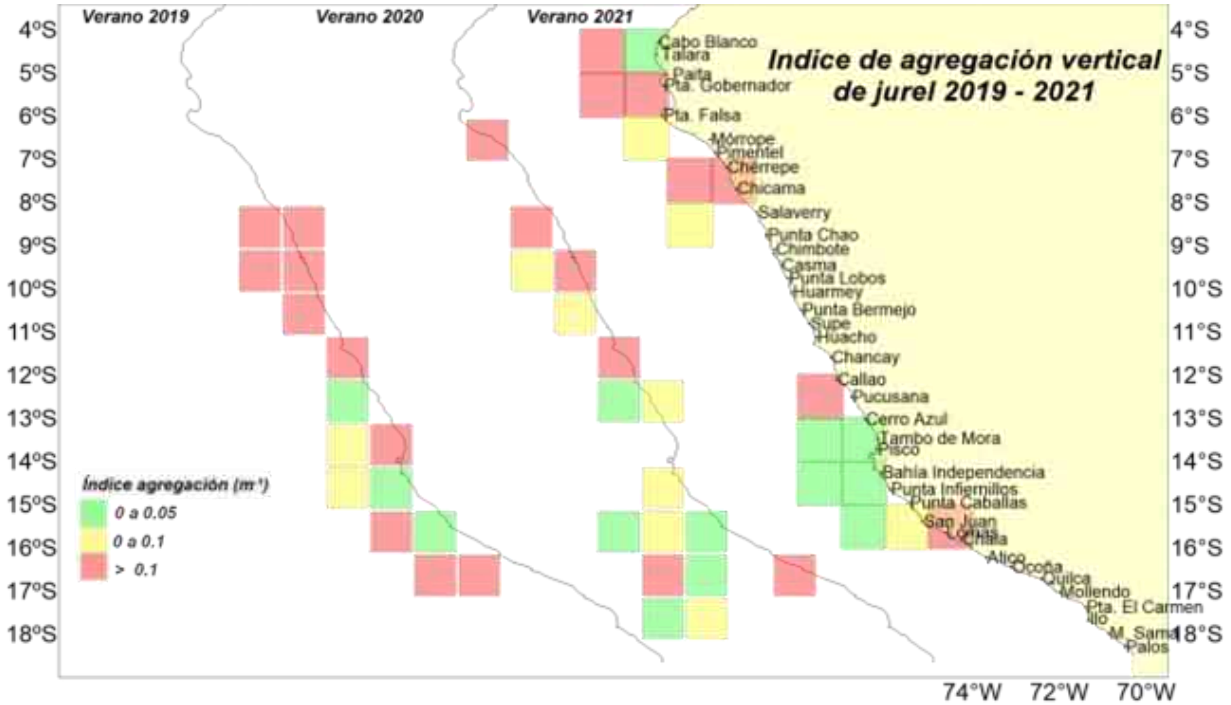

Figure 2.7.1. Aggregation index (IA) results for the summers of 2019 to 2021 calculated from acoustic detections of Jack mackerel made by the fishing fleet and IMARPE.

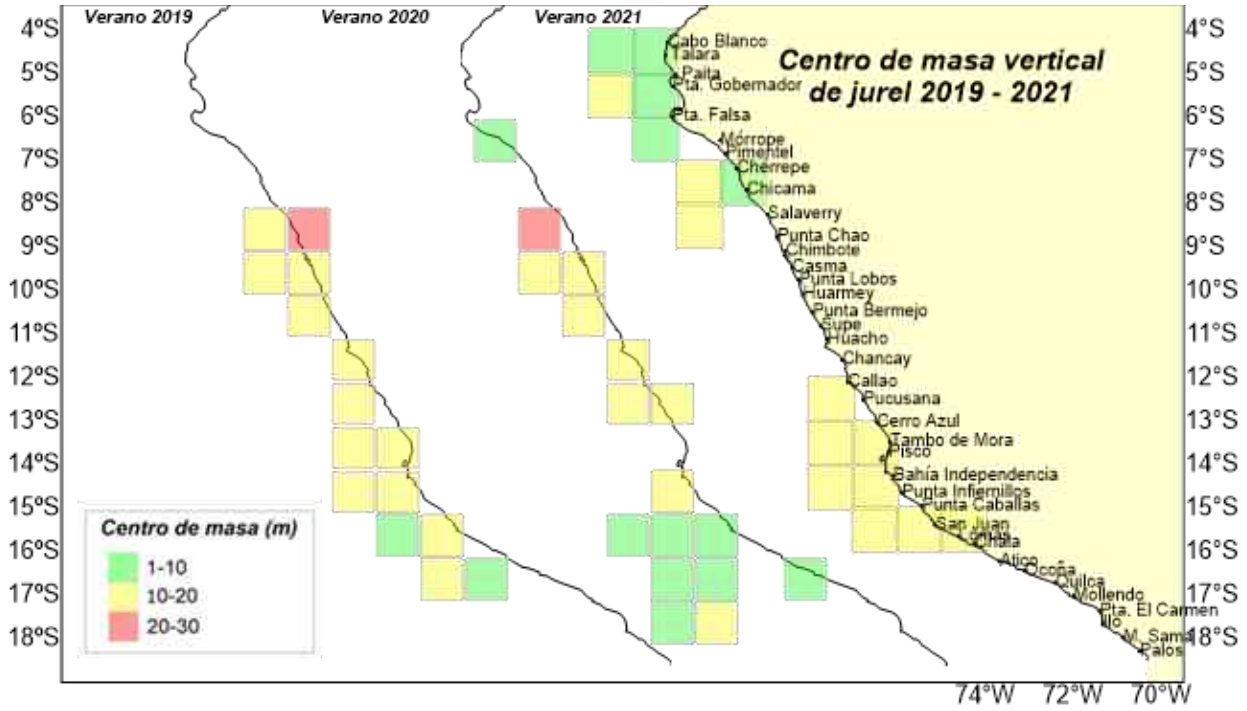

Figure 2.7.2. Results of the center of mass (CM) index for the summers of 2019 to 2021 calculated from acoustic records made on Jack mackerel by the fishing fleet and IMARPE.

3. Description of the abundance of Jack mackerel and Chub mackerel between 1983 and 2021.

3.1. Acoustic estimation of Jack mackerel and Chub mackerel abundance.

In the present case, *abundance* is understood as the quantity of fish (Jack mackerel and Chub mackerel) measured in units of mass (tons) only in the areas of operation of the fishing fleet of the companies associated to the National Fisheries Society (SNP).

Since the first Jack mackerel workshop held in 2011, two methods have been employed to estimate the abundance of these species. The first method is acoustic, i.e., a certain number of vessels participating in the fishery, which are equipped with 120 kHz frequency digital echo sounders to collect information to be analyzed during the workshops. However, given the current restrictions, since March 2020 it has not been possible to collect sufficient information to make a reliable estimate of the acoustic abundance of Jack mackerel or Chub mackerel, or that of macrozooplankton and the determination of the location of the upper limit of the minimum oxygen zone (ZMO), as it has been done on previous occasions.

The second method used is geostatistical, through which all fishing sets made between January 2020 and June 2021 for both Jack mackerel and Chub mackerel were grouped into 8 zones or regions, in order to estimate the centers of gravity and inertia associated with each region. The information was also grouped by weeks (20 effective fishing weeks from January 2020 to March 2021). The average catch per area and week was used as a proxy of fish density (tons/n.mi.^{2}). Thus, the multiplication of the average catch by the inertia (n.mi.) yields an abundance in tons. The methodological details used for the data analysis are described in SNP (2015).

3.1.1. Jack mackerel abundance estimated by IMARPE using acoustic methods

Information on latitudinal acoustic abundance and annual Jack mackerel catches along the Peruvian coast has been updated to June 2021. For this purpose, information from IMARPE acoustic surveys has been used; annual landings data have been collected from the Ministry of Production's web page. Figure 3.1.1.1 presents a Hovmoller diagram of the latitudinal changes in Jack mackerel abundance that has been estimated through acoustic methods between March 1983 and March 2021, in which the total landings in those years are also

indicated. In general, two regimes are observed: one between 1983 and 2002, in which abundance fluctuated between medium and high levels and with a wider latitudinal distribution; and another regime exists after 2002 with abundances varying between medium and low levels, with more restricted latitudinal distributions. However, in recent years there has been a positive trend in abundance, i.e., an increase towards medium levels of abundance. Catches over the same period (1983-2021) also show, in general, better yields in years when abundance has been higher.

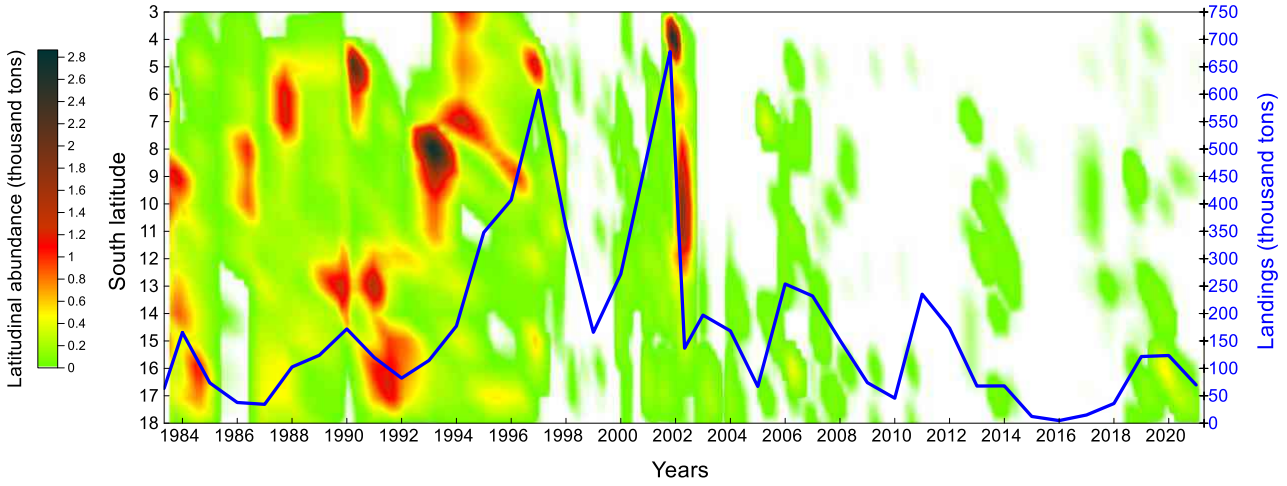

Figure 3.1.1.1 Latitudinal abundance of Jack mackerel along the Peruvian coast, represented by the left vertical axis between 1983 and 2021. Annual catches are represented by the blue line and the right vertical axis. Colors correspond to latitudinal abundances according to the legend on the left side of the figure.

3.1.2. Abundance of Jack mackerel calculated by geostatistical methods.

Figure 3.1.2.1. shows the location and distribution of Jack mackerel fishing sets that have been carried out between January 2020 and March 2021. The industrial Jack mackerel fishing quota of 65,410 thousand tons granted preliminarily by PRODUCE for 2021 was completed in March. The fishing sets carried out have been classified by geographical zones (8) and by weeks (20), in order to calculate the average catch (tons/mn^2), the Center of Gravity (latitude, longitude) and inertia (mn^2) in each of them.

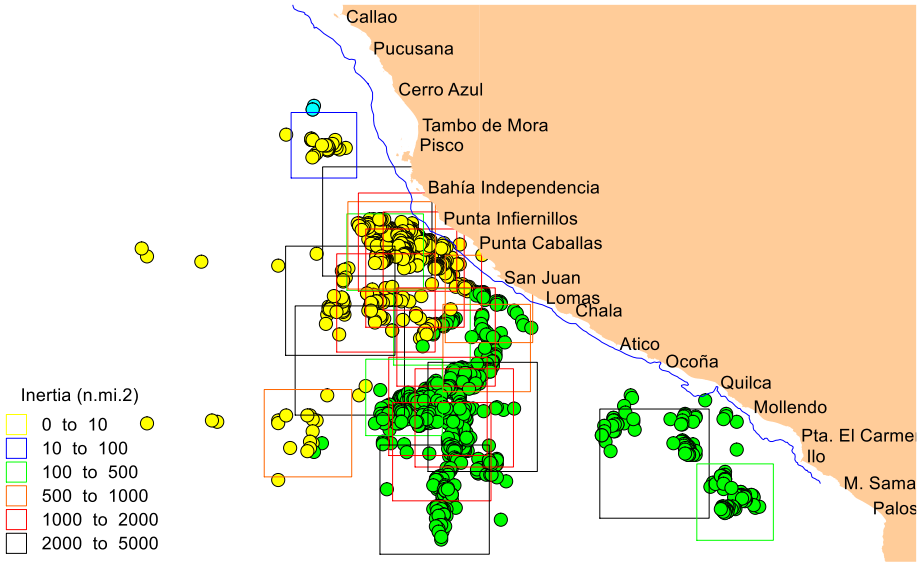

Figure 3.1.2.1. Distribution of Jack mackerel fishing sets and related inertia between January 2020 and March 2021. The light blue circles correspond to the Callao area, the yellow circles to the Pisco area, and the green circles correspond to the southern area. The centers of gravity and magnitude of inertia (indicated by squares according to the legend in the figure) have been determined for each zone and week in order to estimate Jack mackerel abundance in every one of them.

Jack mackerel fishing sets have been observed west of the continental shelf break, from 10 to 200 miles offshore, and between latitudes 13°00'S (Cerro Azul) and 18°20'S (Sama). A total of 1,457 sets were made, with catches ranging from 1 to 800 tons per set. The average catch was 101.83 tons per set. 148,374 tons of Jack mackerel have been caught between January 2020 and March 2021. The average monthly catch in the indicated period was 24,729 tons considering only the months in which the fleet has operated.

Figure 3.1.2.2. shows the abundances (tons) and inertias (mn^2) per week estimated for the distribution of Jack mackerel using geostatistical methods for the 16 weeks in which there was Jack mackerel fishing activity between January 2020 and March 2021. It should be noted that there are no estimates of abundance and inertia in the weeks and months with no catch by the industrial fleet, because these fishing vessels were participating in the 2020 anchoveta fishing seasons. The highest Jack mackerel abundance was estimated during September 2020, with 855 thousand tons, followed by March 2021 with 518 thousand tons. The highest calculated inertia, which is an indicator of Jack mackerel distribution area in the zones where the fleet has operated, was 9,914 mn^2 during September 2021. The month average value of the estimated distribution area is 2,552 mn^2.

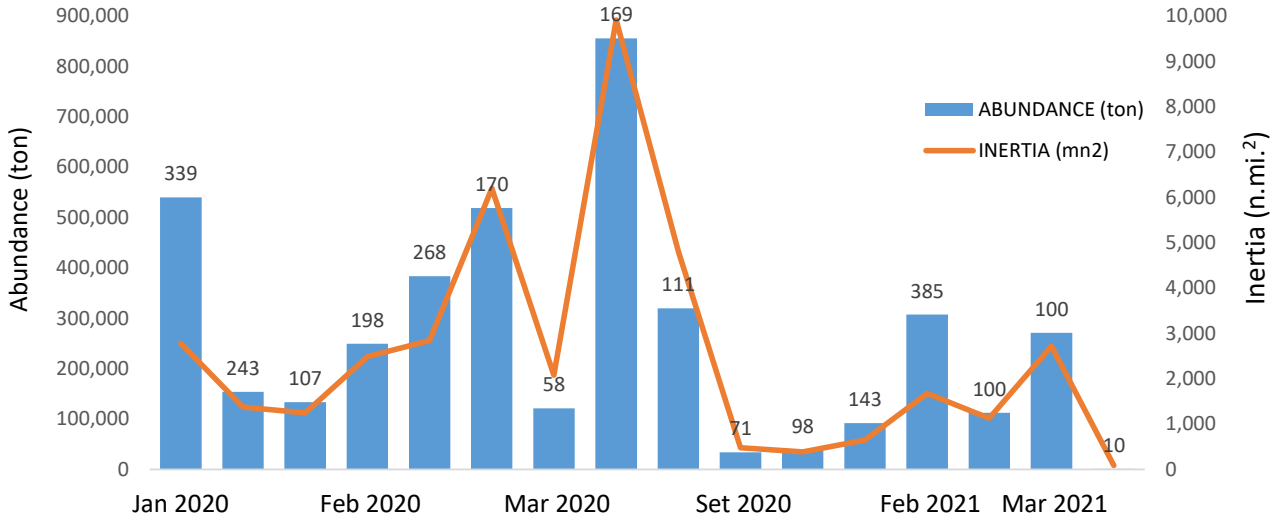

Figure 3.1.2.2. Abundance and inertia of Jack mackerel estimated by weeks between January 2020 and March 2021. The estimates shown in blue bars have been made by summing the partial abundances by regions. The labels above the columns indicate the average catch in each week, which are the values used as proxies for the density in the estimation of the abundance.

3.1.3. Chub mackerel abundance estimated by IMARPE using acoustic methods

Information on latitudinal acoustic abundance and annual catches of Chub mackerel along the Peruvian coast has been updated. For this purpose, information from IMARPE acoustic surveys has been used; annual landings data have been collected from the Ministry of Production's web page. Figure 3.1.3.1. presents a Hovmoller diagram of changes in Chub mackerel abundance between 1983 and March 2021. In general, three regimes are observed: the first was observed between 1983 and 1992, in which abundance was uniform along the entire coast, although with medium levels; the second period was between 1992 and 2002, in which abundance 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 abundance, i.e., an increase towards medium levels. Catches over the same period (1983-2021) show, in general, better yields were obtained in years when abundance has been higher.

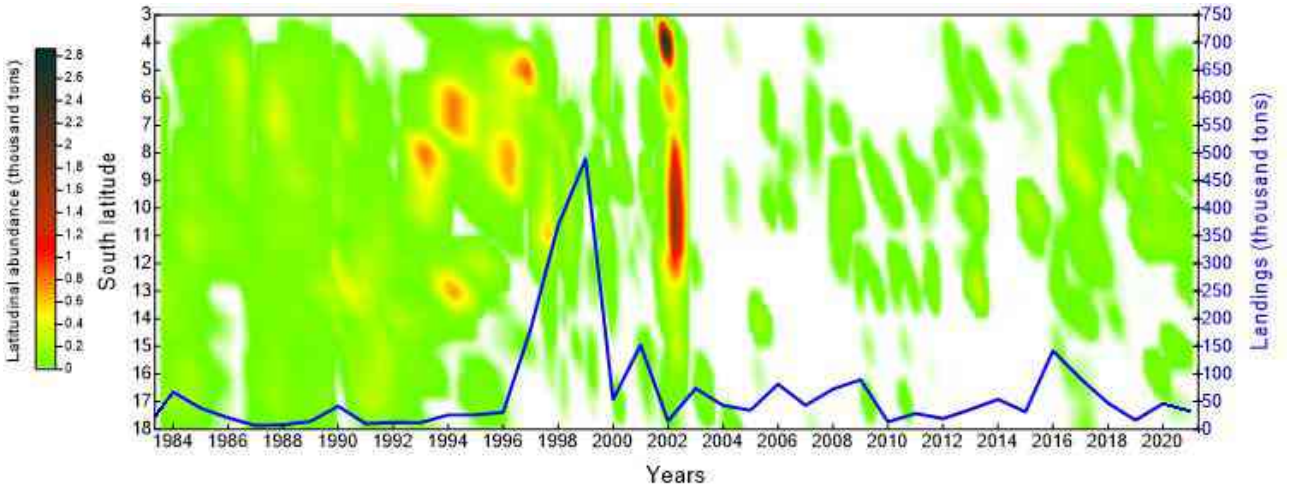

Figure 3.1.3.1. Latitudinal abundance of Chub mackerel along the Peruvian coast, represented by the left vertical axis between 1983 and 2021 (horizontal axis). Catches are represented by the blue line and the right vertical axis. Colors correspond to abundance according to the legend on the left side of the figure.

3.1.4. Chub mackerel catches

Figure 3.1.4.1. shows the location of fishing sets made on Chub mackerel between January 2020 and March 20201. The preliminary 2021 industrial Chub mackerel fishing quota of 68 thousand tons was granted by PRODUCE, which was completed in March. Chub mackerel fishing sets have been observed west of the shelf break, from 10 to 200 miles offshore, and between latitudes 7°30'S (Chicama) and 18°20'S (Sama). A total of 1,488 sets were made, with catches ranging from 1 to 610 tons per set. The average catch was 65.37 tons per set; 97,274 tons have been caught between January 2020 and March 2021. The average monthly catch was 16,212 tons considering only the months in which the fleet operated.

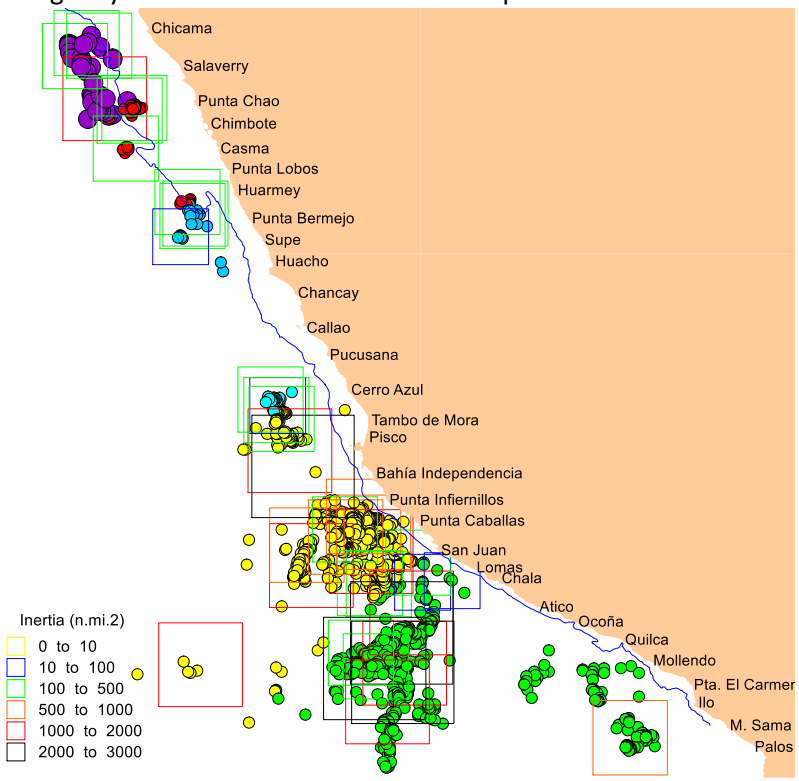

Figure 3.1.4.1. Distribution of Chub mackerel fishing setss and related inertia between January 2020 and March 2021. The colored circles correspond to: purple-Chicama, red-Chimbote, blue-Supe, light blue-Callao, yellow-Pisco, and green-south. The centers of gravity and magnitude of inertia (indicated by squares according to the legend in the figure) have been determined for each zone and week in order to estimate Chub mackerel abundance.

4. Size structure of Jack mackerel and Chub mackerel

Analyses of Jack mackerel and Chub mackerel size structures were carried out using biometric information obtained from fishing sets registered in logbooks aboard the fishing fleet associated to SNP. The size data was obtained from random sampling immediately after each fishing set by using an ichthyometer. In total, it was analyzed the data from 2,945 fishing sets. The data was collected between January 2020 to March 2021. It was constructed the simple frequency of total length after weighting the frequencies regarding the catch per every fishing set. This weighting is the result of calculating the ratio between the weight of every sample and the total caught in its corresponding fishing set.

4.1. Size structure of Jack mackerel

In the 2021 season, between January and March the industrial fleet associated with the SNP recorded juvenile Jack mackerel (< 31 cm) with a percentage of 0.3% in number and 0.1% in weight. The sizes ranged between 20 and 54 cm. This size group presented a main mode of 42 cm and secondary modes at 40 and 44 cm (Figure 4.2.1.).

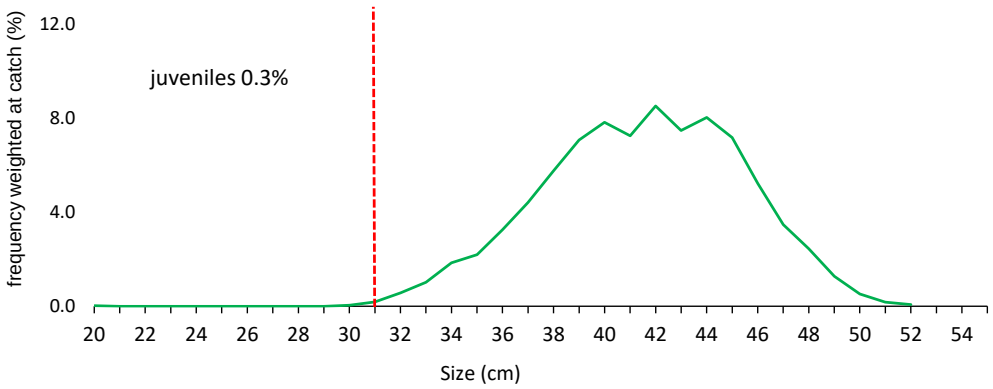

Figure 4.2.1. Size frequency of Jack mackerel during summer 2021

From the modal progression analysis, it was observed that in recent years the industrial fleet has preponderantly caught the same age groups recorded since 2018 (Figure 4.2.2.). The percentage of juvenile Jack mackerel recorded in 2021 was lower with respect to previous years, although the obtained size structure does not represent the total area of the likely distribution of Jack mackerel in Peruvian jurisdictional zone. Furthermore, the 2021 data shown in this report corresponds only to the summer season.

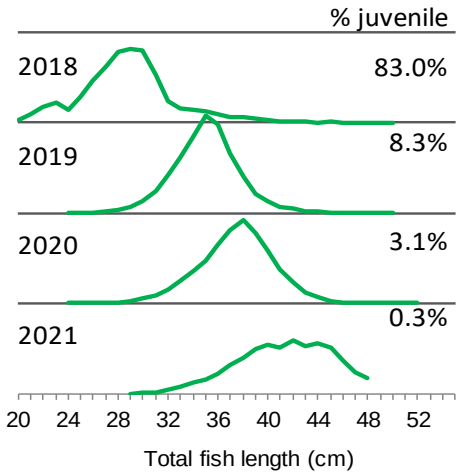

Figure 4.2.2. Size modal progression of Jack mackerel only from areas of operation of the industrial fleet associated to SNP between 2018 to 2021 according to the biometric sampling carried out on board. Note the indication of the percentage of juveniles in each year.

The compared size structure by latitudinal degrees during years 2020 and 2021 indicates a lower proportion of juvenile fish in 2021 (Figure 4.2.3.).

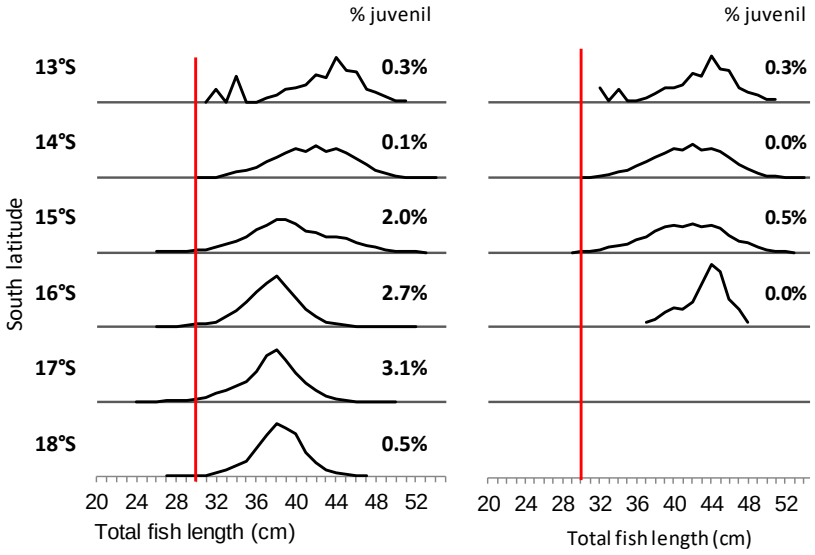

Figure 4.2.3. Latitudinal size structure of Jack mackerel between 2020 and 2021 according to the biometric sampling conducted on board the fleet. The left panel shows the structure observed in 2020, the right panel shows the structure during summer 2021 only. Notice the indication (vertical red line) of the percentage of juveniles in every latitudinal degree.

During January 2020 and 2021, the highest catches of juvenile Jack mackerel occurred, specifically between degrees 15 and 17°S; however, the percentage was low, about 2% of the total catch. During February and March in both years the percentage of juvenile fish was even lower.

However, exploratory fishing trips to the northern zone at the beginning of the 2021 season indicated the dominant presence of juveniles in that zone. Furthermore, the acoustic assessment surve carried out by IMARPE between February and April 2021 also confirms the distribution of juvenile Jack mackerel in the northern zone. Arcos et al. (2004) described that in Chile juvenile Jack mackerels are located offshore, as well larvae of the fish. Nevertheless, according to results of the 2021 summer survey, juvenile Jack mackerel ranging between 3 and 10 cm were observed 10 n.mi. off Bayovar and 20 n.mi. Chicama, while adult Jack mackerel were recorded 50 n.mi. off Callao with a size range between 44 and 50 cm.

4.2. Size structure of Chub mackerel

During summer 2021 the industrial fleet caught 6.1% of juvenile Chub mackerel. The size range varied between 20 and 49 cm in total length. The size structure shows a main mode of 35 cm (Figure 4.3.1).

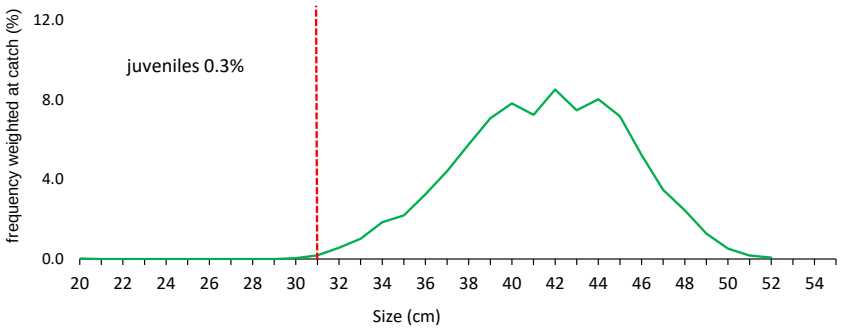

Figure 4.3.1. Size frequency of Chub mackerel during summer 2021

The percentage of caught juveniles in 2021 was lower compared to years 2018 to 2020, though higher compared to 2019. (Figure 4.3.2.). It should be noted that the data for 2021 corresponds only to the summer season.

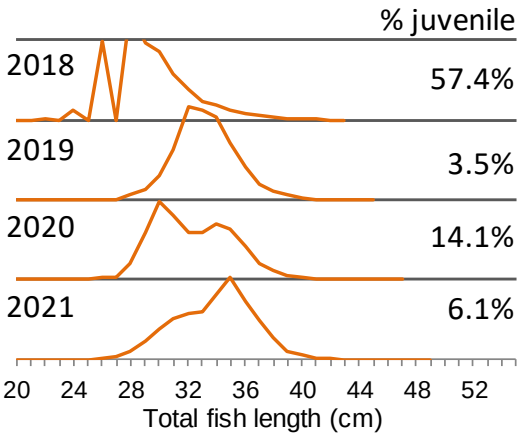

Figure 4.3.2. Size structure of Chub mackerel from 2018 to 2021 according to biometric sampling conducted on board the fleet.

The size structure by latitudinal degree for juveniles and adults (<29 cm) indicates a larger proportion in degrees 7°S and 8°S, while at south of degree 13°S the incidence of juveniles was lower, with the exception of degree 16°S, which had 15% of the total caught juvenile fish (Figure 4.3.3.).

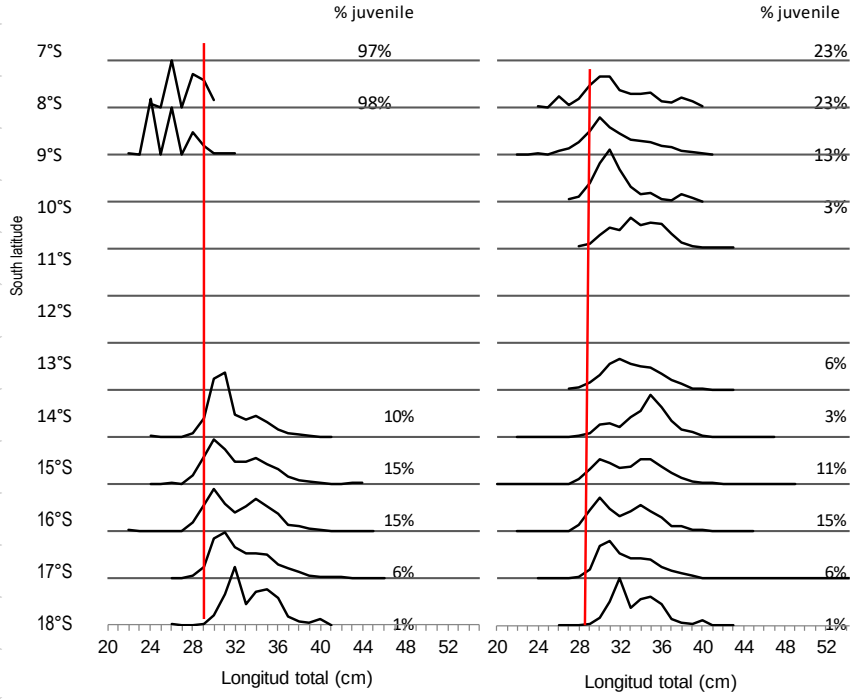

Figure 4.3.3. Latitudinal size structure of Chub mackerel between 2020 and 2021 according to the biometric sampling conducted on board the fleet. The left panel shows the structure observed in 2020, the right panel shows the structure during summer 2021 only. Notice the indication (vertical red line) of the percentage of juveniles in every latitudinal degree.

At the beginning of the fishing season during 2020, catches showed relatively high daily percentages of juveniles in both north (7°S and 8°S) and south (14°S, 15°S, 16°S and 17°S). Instead, during summer 2021, the daily catches were practically 100% adults, though some catch of juveniles remained, particularly in 8°S (Figure 4.3.3.). These results indicate that there was a recruitment of Chub mackerel, mostly in the northern area.

5. Conclusions

5.1. Regarding the habitat of Jack mackerel and Chub mackerel

- The moderate thermal conditions of the last three years have led to a higher availability of Jack mackerel, especially in the southern area. Instead, Chub mackerel increased its availability in the north.
- Summers from 2019 to 2021 -except January 2021- presented higher ocean dynamics than in previous years, which is also associated with a higher availability of Jack mackerel and Chub mackerel, linked to medium and high SLA values.
- During summer 2021, the Jack mackerel fishing grounds were located, as in 2019, south of the Paracas Peninsula along the front between ACF and ASS. Chub mackerel instead had main distribution areas in the north and center zones.

5.2. Regarding the abundance of Jack mackerel and Chub mackerel

- For Jack mackerel acoustic abundance, two regimes are observed between 1983 and March 2021: one between 1983 and 2002, in which biomass fluctuated between medium and high levels; and another regime after 2002 with abundances varying between medium and low levels.
- In recent years there has been a positive trend in Jack mackerel abundance, that is, an increase towards average levels of abundance. Catches over the same period (1983-2021) also show, in general, better yields in years when abundance has been higher.
- For Chub mackerel abundance, three regimes are observed between 1983 and March 2021: one between 1983 and 1992, in which a uniform distribution was observed along the entire coast, although with average abundances; the second period occurred between 1992 and 2002, in which abundance fluctuated between medium and high levels; and a third regime after 2002 with abundances varying between medium and low levels.
- In recent years there has been a positive trend in Chub mackerel abundance, that is, an increase towards medium levels of abundance. Catches over the same period (1983-2021) show, in general, better yields in years when abundance has been higher.

5.3. Regarding aspects related to the size structure of Jack mackerel and Chub mackerel

- During summer 2018, Jack mackerel were observed entering the fishery with a modal group of 28 cm of total length, which during summer 2021 continued to be caught by the fleet. Some evidence exist of young age groups in northern Peru.
- During last years it has been continuously observed the presence of juvenile Chub mackerel, mostly in the northern area.

6. Recommendations

- To promote studies on the variability of the trophic ecology of Jack mackerel, Chub mackerel and other important species such as mesopelagic fish.
- To perform comparative analyses with in situ data regarding satellite oceanography variables, for example, to validate oxycline depth calculations.
- To conduct egg and larvae sampling using Bongo nets or similar from fishing vessels, in order to obtain data to identify or describe the habitat of the early stages of Jack mackerel and Chub mackerel.
- To perform retrospective acoustic analysis of index of aggregation (IA) and center of mass (CM), in order to study changes of density of Jack mackerel and Chub mackerel since the 1980s.

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Annex 1: List of participants in the workshop and in the drafting of the present document (in alphabetical order)

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Pierina Biancato	IHMA
Salvador Peraltilla	SNP
Susan Montero	Diamante

Annex 2: List of reports of Jack Mackerel Habitat Workshops organized by SNP since 2011

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