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South Pacific Regional Fisheries Management Organisation

8th MEETING OF THE SCIENTIFIC COMMITTEE

New Zealand, 3 to 8 October 2020

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Peru Annual Report (Areas under National Jurisdiction)

Peru

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IMARPE

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MINISTERIO DE LA PRODUCCION
PRODUCE

South Pacific Regional Fisheries Management Organisation
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Peru National Report No 2

NATIONAL REPORT ON THE SITUATION OF THE PERUVIAN STOCK OF JACK MACKEREL (FAR-NORTH STOCK) AND THE PERUVIAN FISHERY IN NATIONAL JURISDICTIONAL WATERS, PERIOD JANUARY 2019 – JUNE 2020

by

IMARPE - PRODUCE

This report contains information on the Jack mackerel fish stock and fishery 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.

2020

SUMMARY

In recent years the Peruvian marine environmental conditions have been characterized by a sequence of warmer and cooler than normal events intercalated with relatively short periods of neutral or 'normal' conditions. Since 2014 there has been a weak El Niño in mid 2014, a strong El Niño during 2015 and the first half of 2016, a moderate-coastal El Niño from late 2016 to early in 2017, a weak-to-moderate La Niña from late 2017 to early 2018, and a weak El Niño from very late in 2018 to early 2019. This has been followed by a period of close to neutral thermal conditions, with slightly colder but close to neutral conditions between April and the end of 2019 and warmer but still close to neutral conditions during the first semester of 2020. These environmental conditions have impacted the Peruvian fishery for Jack mackerel (*Trachurus murphyi*) in Peruvian national waters by causing a more dispersed distribution, reduced availability, lower abundance indexes and consequently lower catches of Jack mackerel in Peru between 2014 and the first part of 2018; conversely, the slightly warmer than neutral conditions associated with the weak 2018-2019 El Niño followed by more neutral conditions during the remainder of 2019 and first half of 2020 have favored the expanded distribution farther offshore of denser concentrations, increased availability to the industrial purse seine fleet, much higher abundance indexes and consequently higher catches of Jack mackerel during the second half 2018, throughout 2019 and the first half of 2020. Jack mackerel abundance indexes from scientific surveys and from the fishery have increased noticeably during the second half of 2018 and throughout 2019 and the first half of 2020. CPUE (catch per unit of effort) from commercial fishing and acoustic abundance indices from research surveys in late 2018 and throughout 2019 and early 2020 were similar or well above the maximums observed between 2010 and 2014, and were consistently much higher than those observed during 2015-2017. In late December 2019 IMARPE (Instituto del Mar del Peru) updated the available 2019 Jack mackerel assessment made for the Peruvian (far-north) stock during the 7th meeting of the Scientific Committee (SC07), based on which a range of options for setting the 2020 TAC was included in its advice to the Government, recommending that a TAC for 2020 be established that considers a multiplier of F_{2019} not exceeding 2.0, which corresponded to a maximum estimated F = 0.0652 and a maximum projected TAC = 140 000 t, accepting a risk of 30.9% that the estimated biomass by January 1st 2021 be lower than that estimated for January 1st 2020. A conservative initial TAC for 2020 of 100 000 t was set by the Government in January 2020, and based on an updated assessment of the situation with the newer information and data collected during January, February and March, the initial TAC was reviewed upward by the end of March 2020, bringing the TAC for the whole year to 140 000 t, which was the maximum within the range advised by IMARPE. The main results of an updated 2020 assessment with the same JJM model used during the SC07 but with information and data updated to June 2020 and total catch projected to the end of the year is also presented. These results show an increasing trend in the biomass estimates since 2016 and an overall healthy situation of the Peruvian Jack mackerel stock within the natural low abundance regime as it appears to have been during the last two decades.

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1. INTRODUCTION

This report updates information provided by the Peruvian delegation during earlier meetings of the SPRFMO Science Working Group and the SPRFMO Scientific Committee (IMARPE-PRODUCE 2012, 2012a, 2013, 2014, 2015, 2016, 2017, 2018 and 2019).

The recent situation of the marine environment off Peru is characterized by the sequence of warmer and cooler than normal events intercalated with relatively short periods of neutral or ‘normal’ conditions. Since 2014 there has been a weak El Niño in mid 2014, a strong El Niño during 2015 and the first half of 2016, a moderate-coastal El Niño from late 2016 to early in 2017, a weak-to-moderate La Niña from late 2017 to early 2018 and a weak El Niño from very late in 2018 to early 2019, followed more recently by cold but close to neutral conditions by mid 2019 and warmer but close to neutral conditions by late 2019 and early 2020.

These environmental conditions contributed to the observed low abundance indexes and low catches of Jack mackerel (*Trachurus murphyi*) in Peruvian jurisdictional waters between 2014 and the first part of 2018. While the slightly warmer conditions during the last quarter of 2018 and first half of 2019 associated with a weak 2018-2019 El Niño, and the slightly warm but close to neutral conditions during late 2019 and early 2020 have contributed to a noticeable increase in both the abundance indexes and the monthly catches of Jack mackerel during the second half 2018, most of 2019 and the first half of 2020.

2. THE MARINE ENVIRONMENT

A weak El Niño developed off the Peruvian coast during 2014, which was followed by a short period of close to neutral environmental conditions during late 2014 and by a strong El Niño lasting from April 2015 to April 2016. After a short period of warm but close to neutral conditions, there was an unexpected warming described as a moderate-coastal El Niño, lasting from late December 2016 to May 2017. Then there was a cooling period that develop into a weak-to-moderate La Niña from October 2017 to May 2018, followed by a short period of slightly warmer than neutral conditions that developed into a weak El Niño from late December 2018 to March 2019 and by colder but close to neutral conditions between April and the end of 2019, followed by warmer but still close to neutral conditions during the first months of 2020.

The extent and intensity of the changing thermal conditions in the Peruvian marine environment and the evolution from the more regional weak 2014 El Niño, to the strong 2015-2016 El Niño, the moderate coastal 2017 El Niño, the more regional weak-to-moderate 2017-2018 La Niña, the weak 2018-2019 El Niño, the colder but close to neutral conditions towards the end of 2019 and the warmer but still close to neutral conditions in early 2020 are described by various indexes based on the sea surface temperature (SSTA) observations in oceanic and coastal areas off Peru, such as: the Coastal Index of El Niño (ICEN)) in the Niño 1+2 region, shown in Figures 1; the monthly mean sea surface temperature anomaly (SSTA) in the same Niño 1+2 region, shown in Figure 3 (top panel); the latitudinal distribution of the more local SSTA along the whole Peruvian coastline based on IMARPE (Instituto del Mar del Peru) observations from its own network of coastal laboratories and marine stations in Figure 2; and, the LABCOS index based on the average of the above IMARPE coastal SSTA observations for the whole Peruvian coast, in Figure 3 (bottom panel).

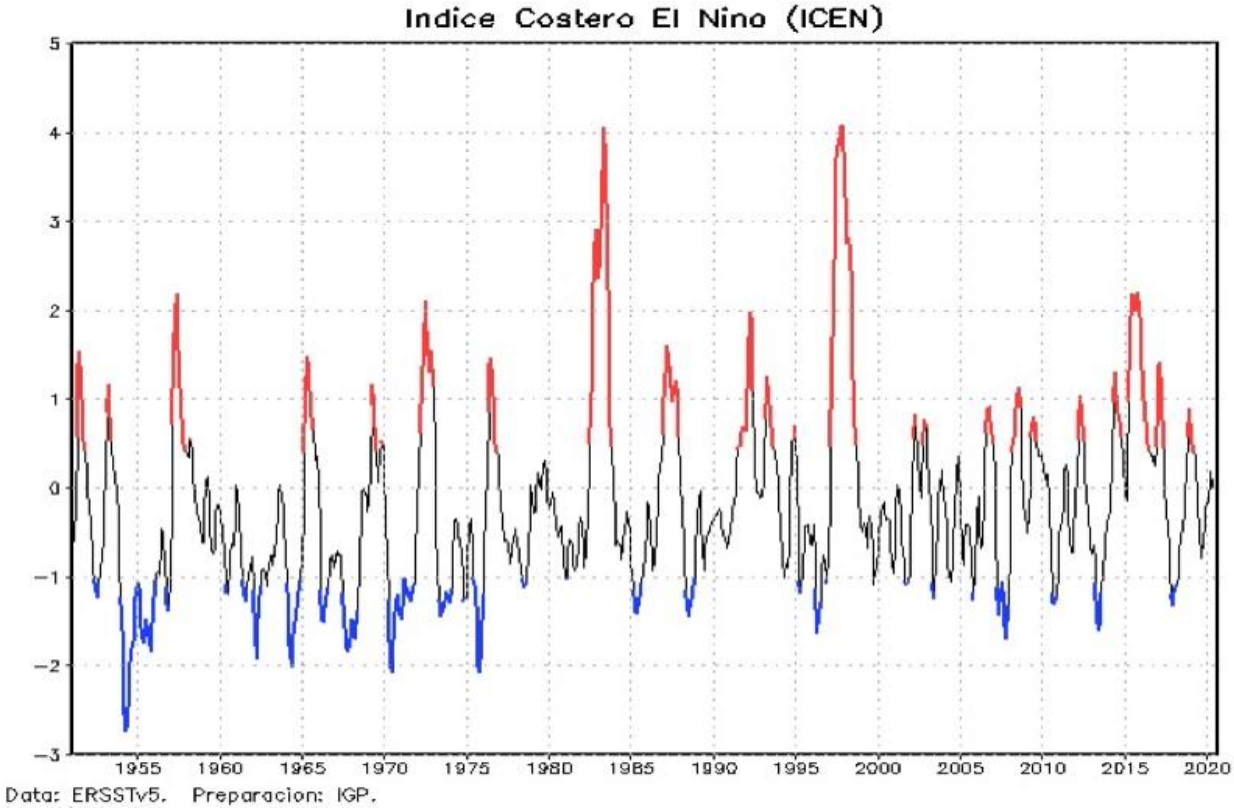


Figure 1.- Coastal Index of El Niño (ICEN) in the El Niño 1+2 region, by month, from January 1950 to June 2020. Calculated as the 3-month moving average of the anomalies of the sea surface temperature in the Niño 1+2 region, referred to a 30-year (1981-2010) monthly mean pattern. Warm El Niño conditions are highlighted in red and cold La Niña conditions are highlighted in blue (data source: NOAA ERSST v5-ICEN)

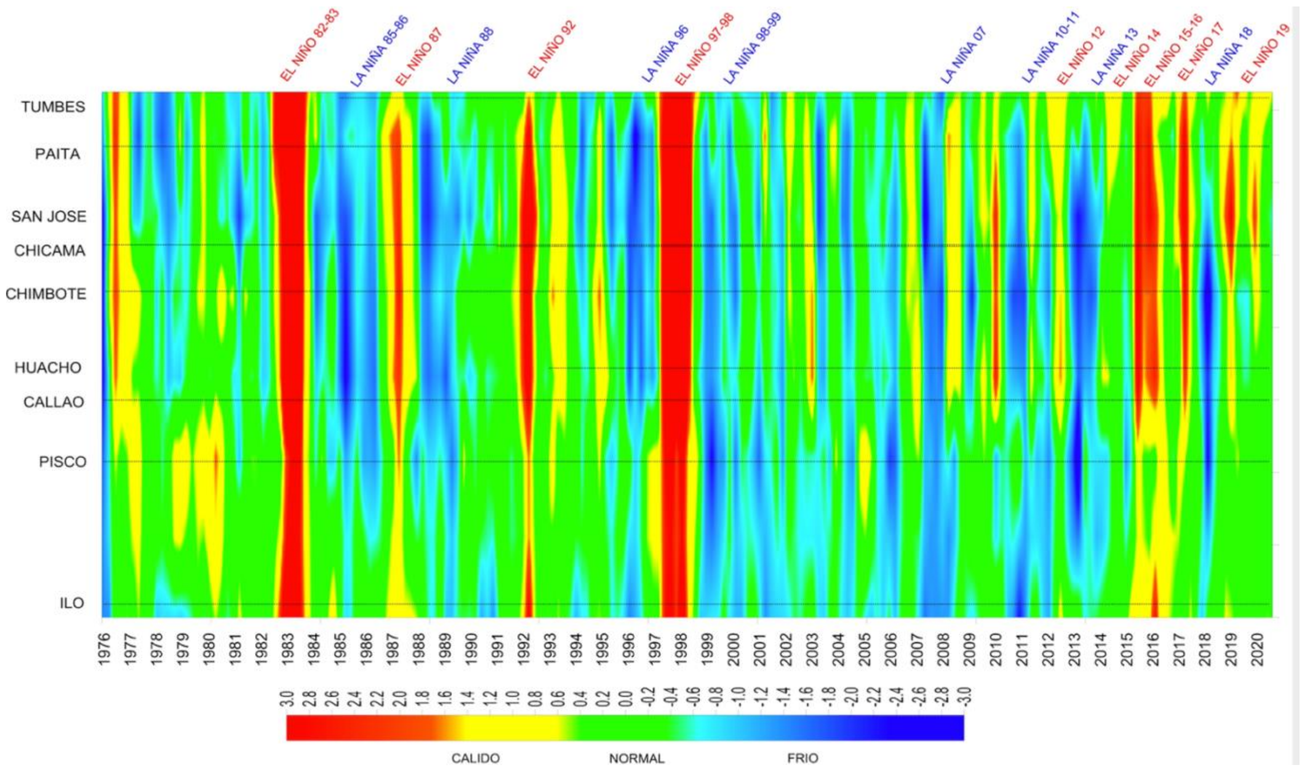


Figure 2.- LABCOS index of the sea surface temperature anomalies (SSTA, in °C) from IMARPE´s coastal laboratories and stations, by latitude along the entire Peruvian coast, years 1976–2020 (until June 2020) (data source: IMARPE)

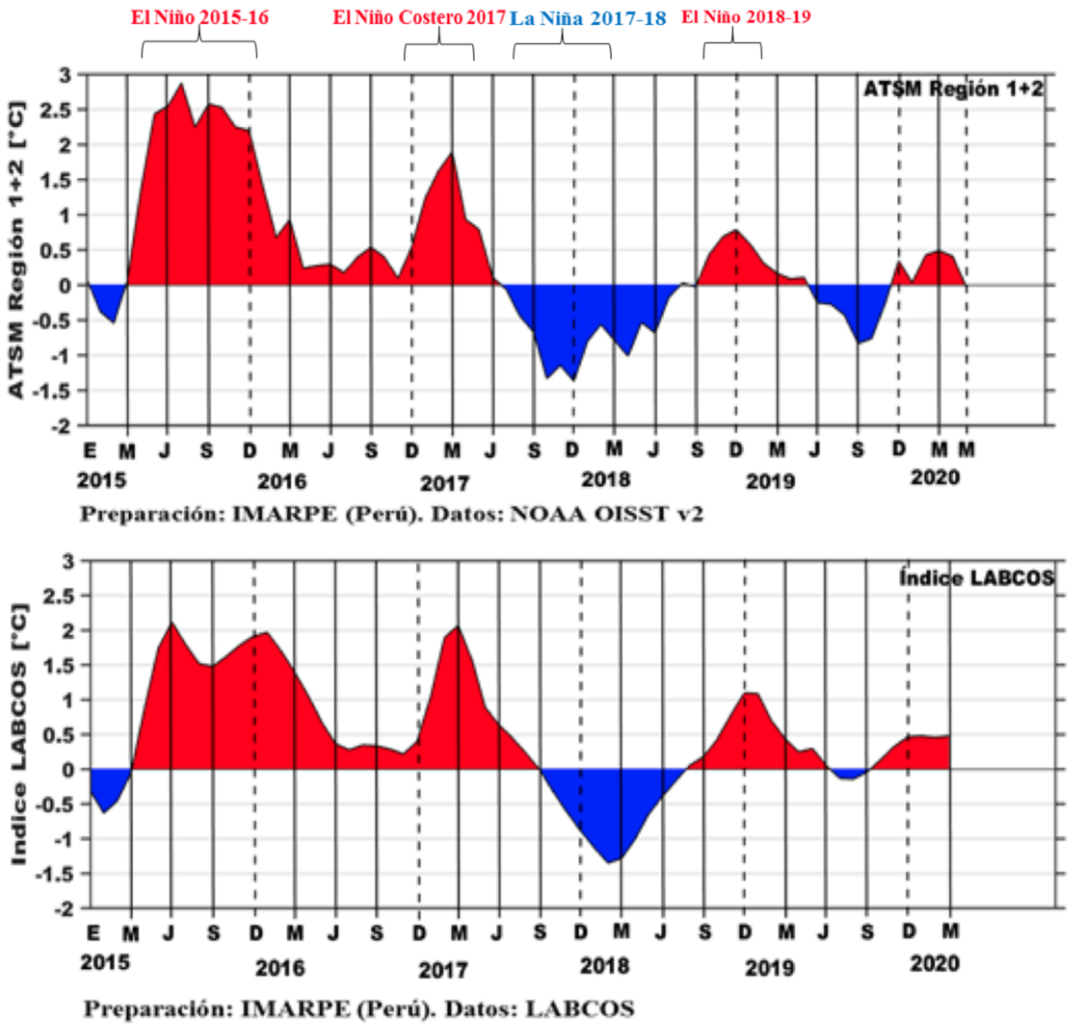


Figure 3.- Mean monthly sea surface temperature anomalies (SSTA, in °C) in the coastal Niño 1+2 region (top panel) and along the Peruvian coastline as reflected by IMARPE's LABCOS index (bottom panel) from January 2015 to May 2020

As can be noted from the evolution of the SSTA indices in Figures 1 and 2, the 2014 El Niño shows up as a weak one in the El Niño 1+2 region and is even weaker along the Peruvian coast, where it had very mild effects limited to the northernmost area. While, as also noted in Figure 3, the strong 2015-16 El Niño was noticeable in the more oceanic El Niño 1+2 area as along the Peruvian coastline, where it lasted a bit longer impacting the whole Peruvian coast, with strongest effects to the north of Callao (12°S). It was, however, not as strong and didn't have as long-lasting warming effects along the whole Peruvian coast as the previous two very strong El Niños of 1982-1983 and 1997-1998.

On the other hand, the moderate 2017 coastal El Niño had much stronger short-term effects in coastal marine and inland areas north of Callao than the strong 2015-2016 El Niño. The warming effects of this moderate 2017 coastal El Niño were lessened and were soon after reversed by cooler than neutral conditions noticeable in the El Niño 1+2 area by July 2017 and along the Peruvian coast by September 2017, developing into a weak-to-moderate 2017-2018 La Niña. During this 2017-2018 La Niña, the maximum negative anomalies were observed much earlier between October-December 2017 in the regional El Niño 1+2 region and much later between February-March 2018 locally along the Peruvian coastline. The cold La Niña conditions then weakened and the SSTA changed into warmer than neutral by September 2018. This warming briefly reached its highest anomalous intensity between December-2018 and January 2019, during the weak 2018-2019 El Niño. From February-March 2019 onwards, we observe a relatively long period of SSTAs close to those of neutral conditions with some alternation between negative anomalies in late 2019 and positive anomalies during the first quarter of 2020 and a clear cooling tendency by May 2020, particularly noticeable in the El Niño 1+2 region.

The environmental conditions and extent of the changes along the Peruvian coast during the development of the weak 2018-2019 El Niño and the latest period of neutral or close to neutral conditions during late 2019 and early 2020 are also illustrated by the distribution of the sea surface temperature (SST) and its anomalies (SSTA) along the Peruvian coast in February-March (summer) 2019 (Figure 4), September-November (spring) 2019 (Figure 5), February-March (summer) 2020 (Figure 6), and the sea surface salinity (SSS) and its anomalies (SSSA) in the same months (Figures 7, 8 and 9).

In February-March 2019, during the weak 2018-2019 El Niño, the SST off the Peruvian coast ranged from 16.8 to 27.5°C, with the highest temperatures (greater than 24°C) in a small area close to the coast to the north of Punta Sal (3°59'S) and an almost continuous offshore band beyond 80 nm distance off the coast from Bayovar (5°50'S) to Morro Sama (18°00'S), associated with the projection of oceanic waters to the coast (Figure 4).

SST below 19.0°C associated with the coastal upwelling processes were found in close to the coast areas, mainly off Salaverry (8°13'S)-Huarmey (10°04'S), Callao (12°03'S), Pisco (13°43'S)-Bahia Independencia (14°14'S), Punta Caballas (14°56')-Chala (15°51'S), Atico (16°14' S) and Ilo (17°40'S). There were also coastal cold conditions with negative anomalies greater than -1°C north of Paita (5°06'S), neutral conditions between Paita and Pacasmayo (7°24´S), warm condition with anomalies greater than +3°C between Pacasmayo and Pisco and beyond 50 nm from the coast off of Supe

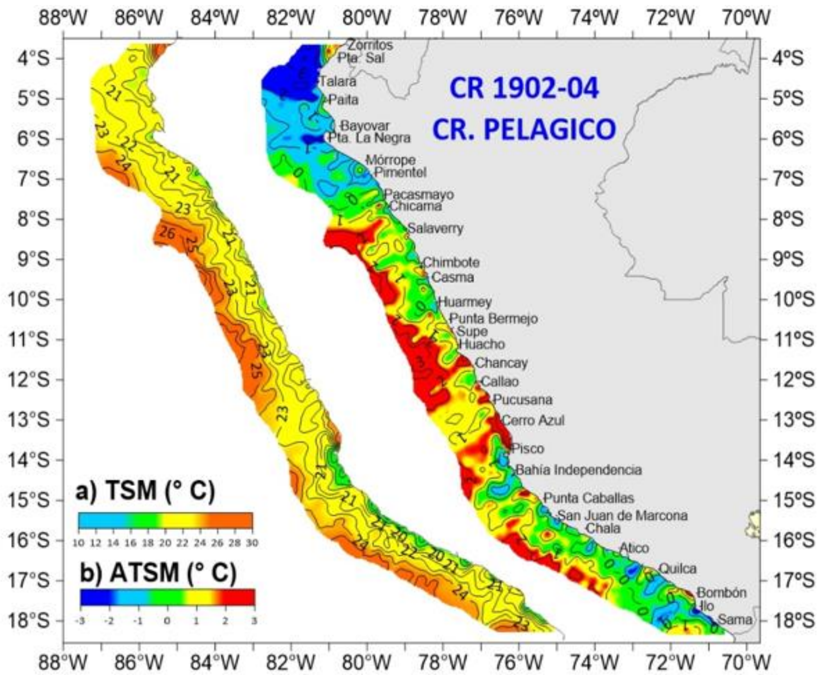


Figure 4.- Distribution of the sea surface temperature (SST, in °C, left panel) and sea surface temperature anomalies (SSTA, in °C, right panel) during February-March 2019, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cruise 1902-03, 12 February - 25 March 2019

(10°48’S)-Callao. Meanwhile, to the south of Pisco, the coastal zone presented a high variability with cold, neutral and warm nuclei, although warm conditions with anomalies of up to +2°C prevailed between 20 and 30 nm from the coast.

During September-November 2019 (Figure 5) the sea surface thermal conditions were predominantly neutral and slightly colder than neutral, with SST along the whole Peruvian coast ranging from 13.4 to 23.3°C. There were only two nuclei with SSTs above 21°C, one off Punta Sal and the other south of Atico, and colder temperatures elsewhere. The SSTs were predominantly lower than 17°C within 50 nm from the coastline between Talara (4°35’S) and San Juan (15°22’S), while beyond the 50 nm the SSTs fluctuated between 17 and 18°C, except for areas north of Talara and south of Chala where the temperatures were higher than 19°C.

This SST distribution was associated with cold conditions between Talara and Chicama (7°51’S) as well as between Bahia Independencia and Quilca (16°47’S), where nuclei of negative SSTAs greater than -2°C were found off Paita-Bayovar and San Juan-Atico. Neutral to slightly cold conditions were found between Chicama and Pisco. Only two small areas with warm conditions (+1°C) were found close to the coast north of Talara and between Quilca and Pta. Bombon (17°11’S).

These environmental conditions represent a significant change in the thermal conditions and anomalies with respect to February-March 2019. Evolving from being warm enough to be categorized as part of the final phase of a weak El Niño during February-March 2019 onto neutral to slightly cold conditions in September-November 2019.

During February and March 2020 (Figure 6) the SST values were between 16.6 and 27.1°C with SSTs lower than 20°C in various areas within 10 nm from the coast and particularly between Casma (9°28’S) and Huarmey, Pisco and San Juan, and Atico and

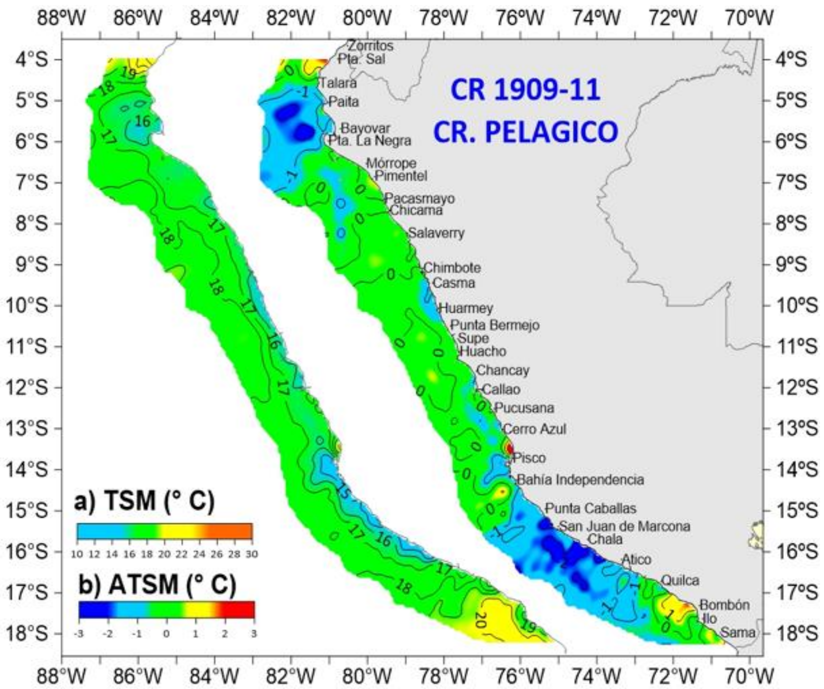
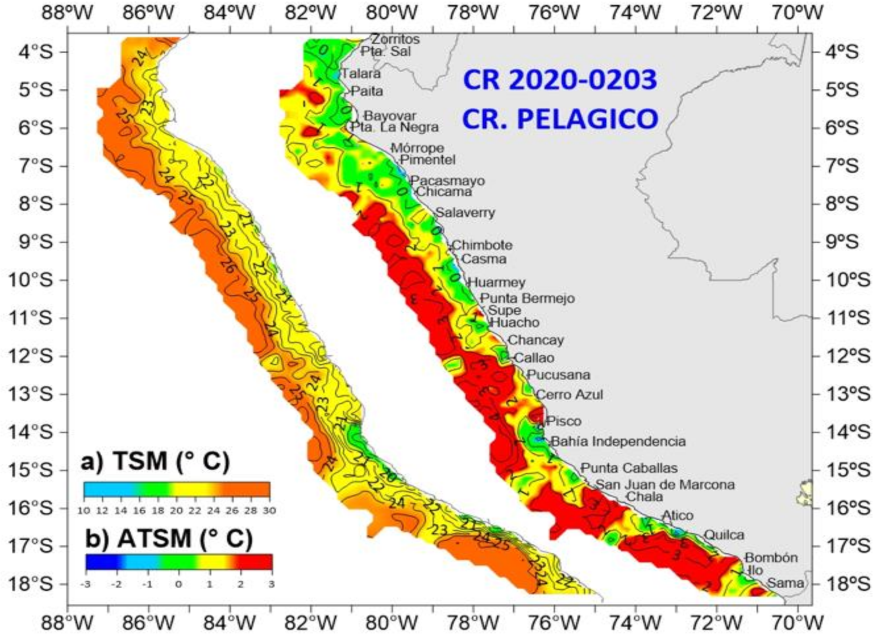


Figure 5. - Distribution of the sea surface temperature (SST, in °C, left panel) and sea surface temperature anomalies (SSTA, in °C, right panel) during September-November 2019, as observed during IMARPE’s Hydroacoustic Survey for the Assessment of Pelagic Resources, Cruise 1902-03, 29 September- 11 November 2019

Mollendo (17°00’S). SSTs above 25°C were found beyond 50 nm from the coast off Bahía Independencia and beyond 20 nm from the coast off Mollendo. The SSTAs evidenced a predominance of warm conditions in the whole area, with cold anomalies to the north of Chicama and warm anomalies that in some sectors exceeded +2.0° and even +3.0°C to the south of Chicama. These somehow atypical conditions during February-March 2020 were favored by strong winds during the first fortnight of February, which caused a drop in SSTs and SSTAs, mainly in the north, and was followed by the arrival of a warm Kelvin wave and changes in atmospheric circulation that included episodes of weakening of the southeast wind, favoring the intrusion of warm waters from the north and west and anomalous warming along the Peruvian coast.

Figure 6.- Distribution of the sea surface temperature (SST, in °C, left panel) and sea surface temperature anomalies (SSTA, in °C, right panel) during February-March 2020, as observed during IMARPE’s Hydroacoustic Survey for the Assessment of Pelagic Resources, Cruise 2002-03, 15 February - 27 March 2020



The spatial distribution of the sea surface salinity (SSS) during February-March 2019 (Figure 7) and the SST during the same period (Figure 4) suggest an active and extended mixing processes to the north of Mórrope (6°31’S) between equatorial surface waters, subtropical surface waters and waters from the coastal upwelling, while closer to the coastline the mixing was between subtropical surface waters, waters from the coastal upwelling and waters from the continental discharge (rivers). The subtropical surface waters were located mostly beyond the 20 nm from the coast south of Mórrope.

On average, during February and March 2019 the sea salt concentration was higher than expected, except for a few areas adjacent to river basins where salt concentration was below their climatological average, such as between Atico and Pta. Bombon, where there was an extended area of negative SSSA, possibly due to the increased contribution of fresh water from rivers.

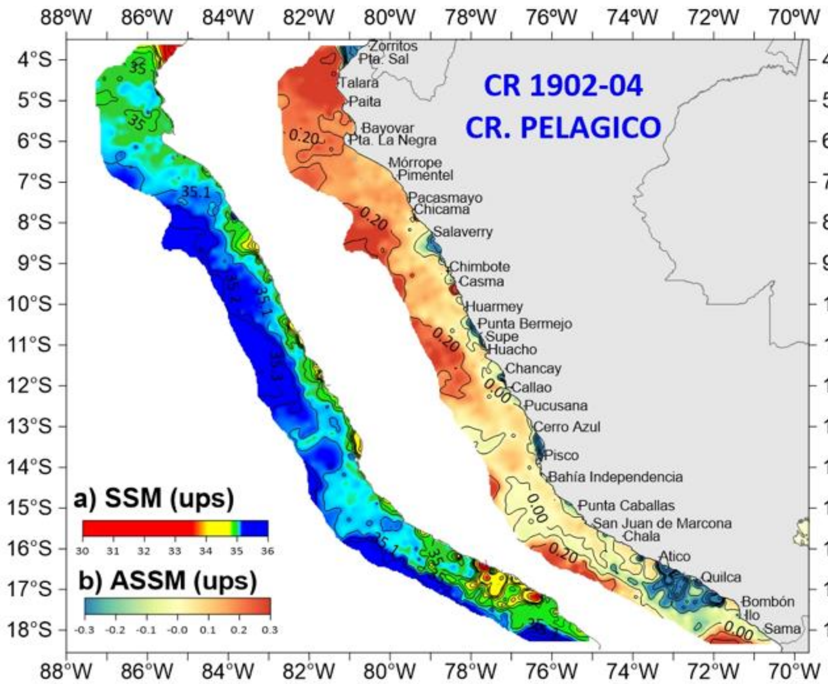


Figure 7.- Distribution of the sea surface salinity (SSS, in ups, left panel) and the anomaly of the sea surface salinity (SSSA, in ups, right panel) during February-March 2019, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cruise 1902-03, 12 February - 25 March 2019

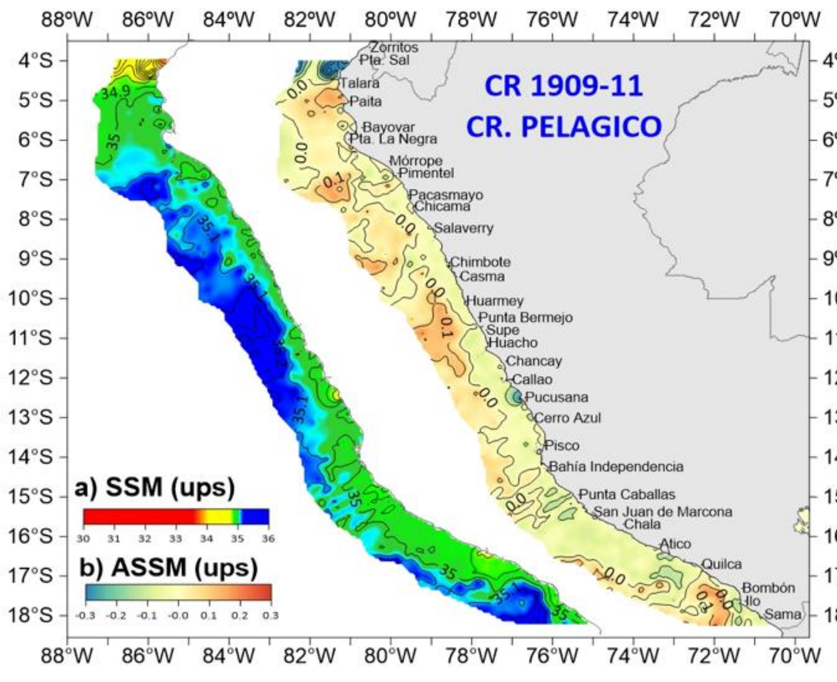


Figure 8.- Distribution of the sea surface salinity (SSS, in ups, left panel) and the anomaly of the sea surface salinity (SSSA, in ups, right panel) during September-November 2019, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cruise 1902-03, 29 September- 11 November 2019

The distribution of the SSS during October-November 2019 (Figure 8) shows a prevalence of neutral saline conditions with tropical surface waters located in the north, off Punta Sal, equatorial surface waters off Talara and waters from the coastal upwelling distributed along the entire coastal area south of Paita, extending as far as 80 nm from the coast in the Pisco-Atico area. This represents a major change with respect to what was observed during February-March 2019, when the coastal upwelling waters were restricted to very coastal areas. But the coastal upwelling waters expanded and the subtropical surface waters retreated to the west, generating large areas of mixing waters by October-November 2019. During the same time, in the area between Talara and Pimentel (6°50’S), the mixing processes was caused by the interaction between equatorial surface waters, subtropical surface waters and coastal upwelling waters, but along the coastal areas from Pimentel to the south the mixing process was produced by the interaction between subtropical surface waters and waters from the coastal upwelling. River discharge was low and didn’t contribute much to the water mixing process, which is typical for the season.

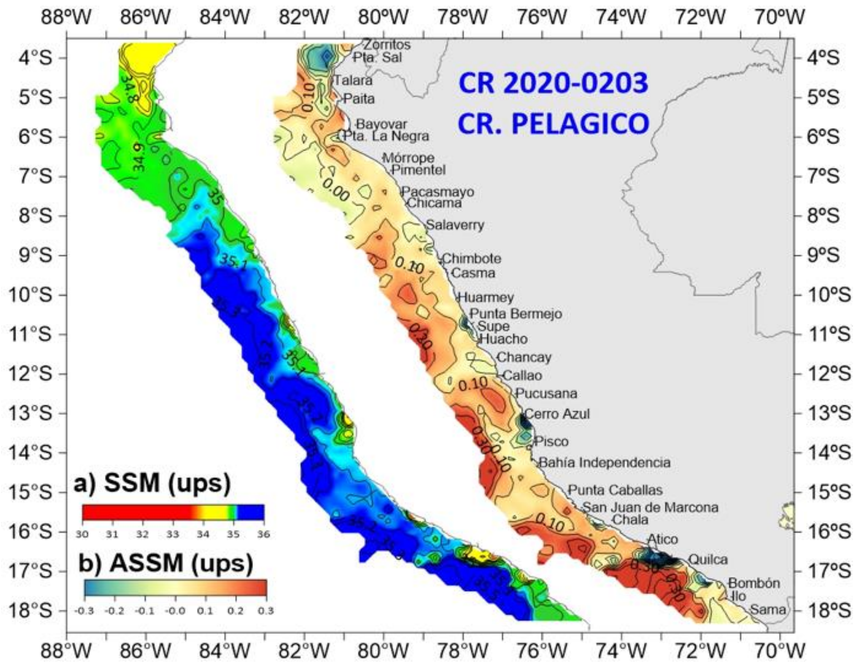


Figure 9.- Distribution of the sea surface salinity (SSS, in ups, left panel) and the anomaly of the sea surface salinity (SSSA, in ups, right panel) during February-March 2020 as observed during IMARPE’s Hydroacoustic Survey for the Assessment of Pelagic Resources, Cruise 2002-03, 15 February - 27 March 2020

Then, by February-March 2020, the distribution of the sea surface salinity (Figure 9) was also atypical for this time of the year, with the presence of equatorial surface waters north of Talara; a mixture of equatorial surface waters and subtropical surface waters between Talara and Bayovar; and a mixture of equatorial surface waters, subtropical surface waters and waters from the coastal upwelling between Bayovar and Chicama. While the subtropical surface waters were unusually close to the coast from Pimentel to the south, restricting the coastal upwelling waters to more coastal areas where some strong upwelling spots persisted. Also, there was less continental discharge, and the influence of the subtropical surface waters was greater than during the same period in 2019; and, in general, the saline concentrations were higher during February-March 2020 than during the same period in 2019.

3. CHARACTERIZATION OF THE STOCK

3.1. Spatial distribution

The alternating warmer and cooler than normal environmental conditions that have prevailed along the Peruvian coast since 2014 have caused a more or less persistent displacement and dispersion of the Jack mackerel concentrations until mid-2018, having favored the presence of denser concentrations in late 2018 and, in particular, during 2019 and the first part of 2020.

During 2014 and particularly during 2015, 2016 and 2017, Jack mackerel concentrations of commercial interest were only found within 10 to 20 nm distance from the coast, being within reach of the artisanal and small-scale vessels but outside the reach and usual fishing grounds of the industrial purse seine fleet. This spatial distribution of Jack mackerel concentrations during 2014, 2015, 2016 and early 2017 was closely related to the effects of the weak 2014 El Niño, the strong 2015-16 El Niño and the moderate 2017 coastal El Niño, of which the related proximity to the coast of the subtropical surface waters and the almost disappearance of the front of mixed subtropical surface waters with cold coastal waters, where Jack mackerel tends to concentrate.

The situation didn’t change much during late 2017 and the first part of 2018 during the weak-to-moderate 2017-2018 La Niña as far as the distribution and dispersal of the Jack mackerel concentrations of commercial interest is concerned. This continued to be available only to artisanal and small-scale fleets closer to the coast and too dispersed and in too small-size schools to be attractive to the industrial fleet farther offshore.

This situation changed during late 2018 and particularly during early 2019 as the slightly warmer than normal conditions associated with the weak 2018-2019 El Niño developed, and rapidly faded away to turn into slightly cold but close to neutral conditions by June-September 2019 and into warm but also close to neutral conditions from October 2019 throughout June 2020. This has favored the presence of denser Jack mackerel concentrations within the easier reach of the industrial purse seine fleet at 20 to 80 nm from the coast, particularly between Chimbote (9°04'S) and Pisco (13°43'S) during 2019 and between Pisco and Morro Sama (18°00'S) during the first half of 2020.

3.2. Age and growth

The few age readings and length frequency distributions analyzed by the conventional methods between 2014 and first months of 2020 fall within the range of the growth parameters of the von Bertalanffy growth function in regular use by IMARPE, where: L_∞ = 80.77 cm total length, k = 0.1553 y^{-1} and t_0 = -0.3562, originally estimated by Dioses (1995) and confirmed by more recent observations and growth estimates by Dioses (2013), Goicochea *et al*. (2013) and Diaz (2013).

3.3. Reproductive aspects

The observed monthly variability of the gonadosomatic index (GSI) of Jack mackerel in Peruvian waters (Figure 10) indicates that after the above normal 2012-2013 reproductive cycle, the intensity of the reproduction process has been generally low and/or out of phase with respect to the 2002-2012 mean values taken as standard. The monthly GSI throughout most of 2018 were amongst the lowest on record, making the

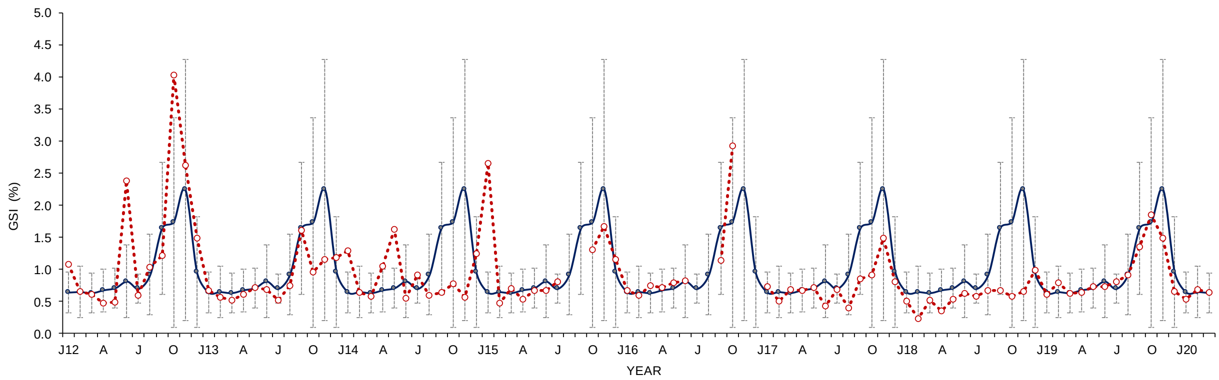


Figure 10.- Monthly variability of the Gonadosomatic Index (GSI) of Jack mackerel larger than 26 cm TL caught in Peruvian jurisdictional waters. The dark line and markers represent the long-term monthly mean for the years 2002-2012, taken as the standard and the grey vertical lines represent their respective standard deviations. The red circles and broken lines are the actual observed monthly values from January 2012 to March 2020. Updated from Perea *et al.* (2013)

2018-2019 reproductive cycle a flattened one. It is noted that this flattened reproductive cycle falls right in between the weak-to-moderate La Niña that lasted from October 2017 to May 2018 and the weak 2018-2019 El Niño that lasted from December 2018 to March 2019. However, the 2019-2020 reproductive cycle has been almost normal, with GSI values very close to the long-term mean values taken as standard. As described above, the prevailing environmental conditions during this 2019-2020 reproductive cycle were neutral or very close to neutral.

3.4. Trophic relationships

The updated information on preys in its food content (Figure 11) continues to confirm that Jack mackerel is an opportunistic forager, with changes in their diet most likely indicating changes in their ecosystem (Konchina 1981; Muck and Sanchez 1987; Alegre *et al*. 2015) and it is also confirmed that there is a great diversity of preys in the diet of Jack mackerel off Peru as it forages on a large variety of taxa (their known preys include more than 60

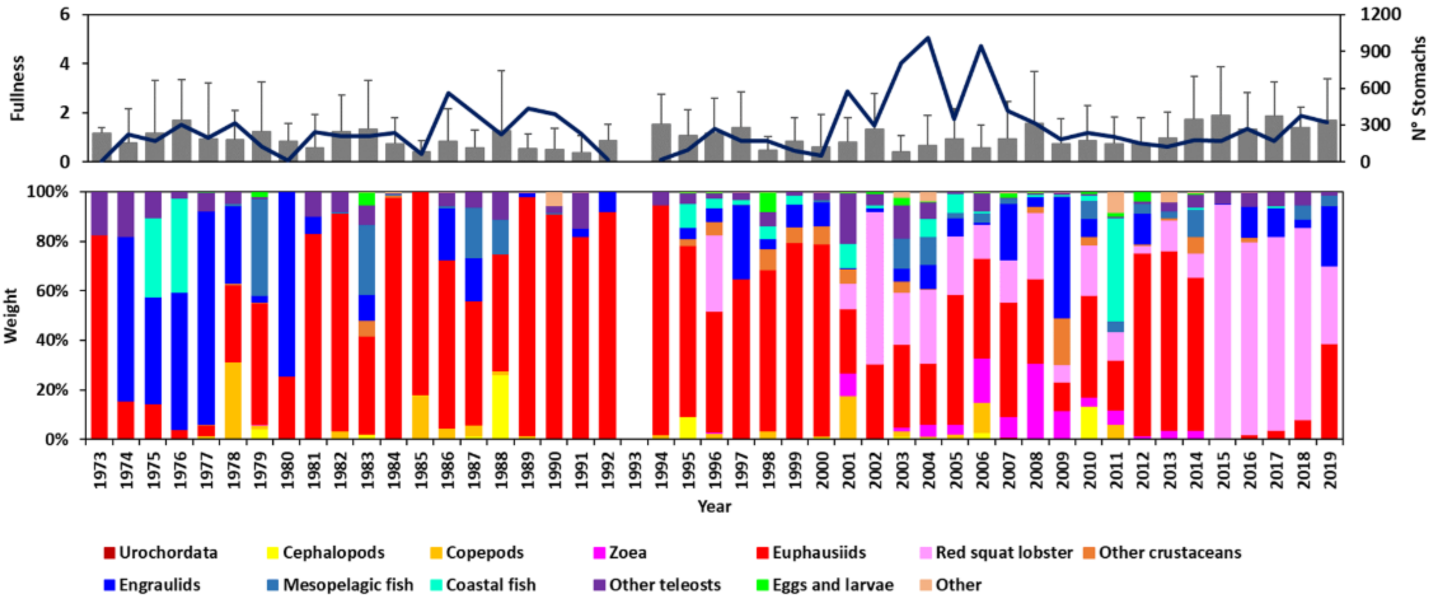


Figure 11.- Index of fullness (in %, vertical bars, top panel), sample size (solid lines, top panel) and proportion of preys (vertical bars, lower panel) in stomach content of Jack mackerel *Trachurus murphyi* off Peru from 1973 to 2020. Updated from Alegre *et al*. (2013, 2015)

taxa groups), although during most of the last 46 years there has been a clear predominance of euphausiids.

The dominance of euphausiids in the diet of Jack mackerel is more evident during the decades of the 1980s and 1990s, corresponding to a slightly warmer multidecadal period, while a more diversified diet is observed during the slightly colder period of 2001 to 2014. During these slightly colder years, euphausiids continued to be an important component of the Jack mackerel diet, although there was an increased presence of other species, especially zoeas and squat lobster (*Pleuroncodes monodon*), with *P. monodon* becoming the dominant component of the Jack mackerel diet during the warmer years of 2015 to 2019, since it has been particularly abundant, probably benefitting from the influence of the strong 2015-2016 El Niño, the moderate 2017 coastal El Niño and the weak 2018-2019 El Niño.

The increase of *P. monodon* in the diet of Jack mackerel since 2001, and particularly since 2015 is consistent with the noticeable increase in the abundance of *P. monodon* observed off Peru since the late 1990s (Gutiérrez *et al*. 2008), while their clearer dominance since 2015 might also be associated with the proximity to the coast of the subtropical subsurface waters at 10°S and 15°30'S and of the cold coastal waters from 16°S south, and the coastal distribution of most of the catches (and samples) taken in 2015-2018. This has changed during 2019, where there was an increase in the proportion of euphausiids and bony fish in the observed diet of Jack mackerel. This is consistent with the extended areas of mixed coastal upwelling waters and subtropical surface waters and the more offshore distribution of Jack mackerel schools observed during 2019.

4. DESCRIPTION OF THE FISHERY

There are two main groups of vessels fishing for Jack mackerel in Peruvian national waters: the industrial purse seine fleet, with 104 industrial purse seine vessels with holding capacities larger than 36.2 m^3; and, the small-scale and artisanal fleets, with smaller vessels having a maximum hold capacity of 32.6 m^3. The small-scale fleet includes around 100 small, lightly mechanized, purse seine vessels with an average hold capacity of 12 m^3; and the artisanal fleet may include as many as 18 000 small vessels using a large variety of manually operated fishing gears, of which around 500 boats with an average hold capacity of 8 m^3 are the ones most frequently fishing for Jack mackerel, mostly with small purse seines or hock and line.

The industrial purse seiners participate in two types of pelagic fisheries. One for anchoveta (*Engraulis ringens*), used mostly for fishmeal; and, the other one for Jack mackerel, also targeting on chub mackerel (*Scomber japonicus*), bonito (*Sarda chiliensis*) and other mid-size pelagics such as sardine (*Sardinops sagax*); when available, all of them are used exclusively for direct human consumption. These fisheries take place during different fishing seasons, adopt different searching (and fishing) strategies, use different types of purse-seines (with mesh-size of 13 mm for anchoveta and 38 mm for mid-size pelagics), as well as different maneuvering and storage holding on board. The fleet cannot fish for both (*i.e.:* anchoveta and mid-size pelagics) during the same trip; and it has been noted that whenever the fishing season is open for the two groups (anchoveta and mid-size pelagics), the industrial purse seine fleet clearly prefers to fish for anchoveta.

The small-scale and artisanal fleets are far more flexible and opportunistic, and target indistinctly a large variety of species depending on their availability and market demand.

4.1. Catch and CPUE trends

Landings from catches of Jack mackerel in Peruvian waters between 2011 and 2017 were in continuous decline, and between 2015 and 2017 annual catches were amongst the lowest on record (Figure 12). As already noted, low catches in those years appear to be associated with the displacement and dispersion of the Jack mackerel concentrations due to the impacts of the recent weak 2014 El Niño, the strong 2015-2016 El Niño, the moderate 2017 coastal El Niño and the weak-to-moderate 2017-2018 La Niña.

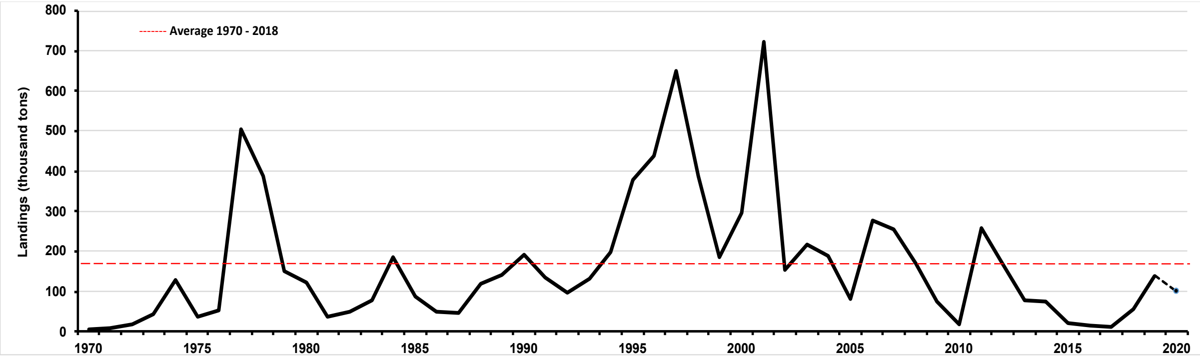


Figure 12.- Annual landings of Jack mackerel (*T. murphyi)* in Peru, years 1970-2019, plus January-July 2020

Catches during the first part of 2018 were also low but increased slightly during the second half of 2018 and had a clearer increase during 2019 and the first half of 2020, getting close to, but still under to the historic average for 1970-2018. To a great extent this recent increase in catches was associated with the closer to neutral environmental conditions that prevailed during this latest period, which may have favored the increased availability of Jack mackerel in more concentrated and larger schools, more attractive to the industrial purse seine fleet.

The industrial purse seine fleet didn't target much on and didn't report significant catches of Jack mackerel between 2014 and early 2018. This was mainly due to the scarcity of attractive enough concentrations of Jack mackerel, but also due to the high demand for, good price, increased abundance and higher availability of other species, in particular anchoveta (*E. ringens*), chub mackerel (*S. japonicus*) and bonito (*S. chiliensis)*. This resulted in most of the catches of Jack mackerel that were reported during this period being taken by smaller vessels of the artisanal and the small-scale purse seine fleets.

Towards the end of 2018, throughout 2019 and the first part of 2020 the total and monthly catches of Jack mackerel significantly increased with respect to the previous three years and, as shown in Figure 13, this was due to the high catches in selected months during the second part of 2018, during 2019 and first months of 2020. These particularly high catches were mostly made by the industrial purse seine fleet during the relatively short

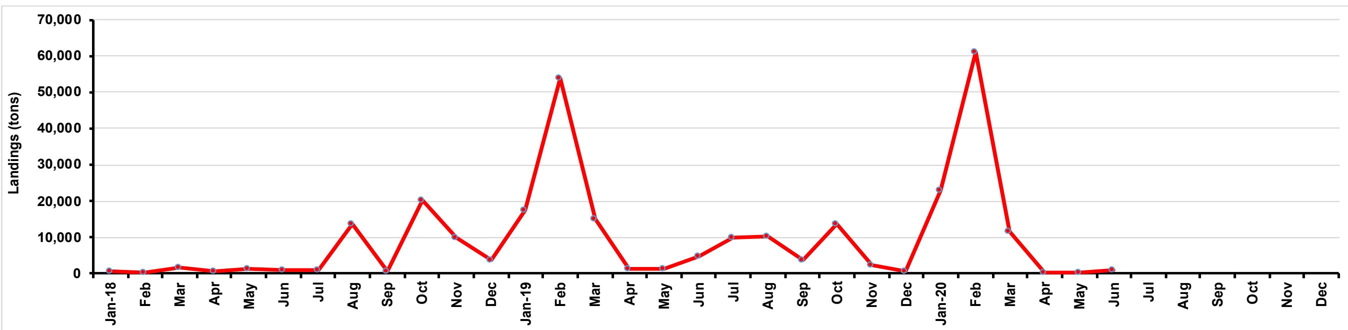


Figure 13.- Monthly landings of Jack mackerel (*Trachurus murphyi*), total Peru, between January 2018 and June 2020

periods when fishing for Jack mackerel by the industrial purse seine fleet was allowed and when there was no fishing of anchoveta by this fleet. Monthly catches of Jack mackerel by the artisanal and small-scale fleets are usually much lower and tend to depend more on local market demand and availability of Jack mackerel concentrations in coastal areas but, nevertheless, the 2019 monthly and annual Jack mackerel landings by these fleets has been the highest on record.

Within the first three months of 2019, the total catches of Jack mackerel almost doubled those of the whole year in 2018 and six-fold of those taken by year between 2015 and 2017. Dewspite all of this, fishing for anchoveta (*E. ringens*) and other pelagics has been competing for the attention of the industrial purse seine fleet, as partly evidenced by the drop in monthly catches in March and April 2019 in coincidence with the opening of the anchoveta fishing season, which happened to remain closed during January and February 2019 and the first part of March 2019. A similar situation occurred during the early months of 2020.

The above recent increase in monthly Jack mackerel catches during 2018, 2019 and 2020 is also explained by the increasing trend in CPUE abundance indexes from both the industrial and the artisanal fleets, as shown in Figure 14. As can be noted, the monthly CPUE (in tons per trip) of both fleets increased during August 2018 and had remained at high levels with a generally increasing trend throughout the second part of 2018, the whole of 2019 and the beginning of 2020.

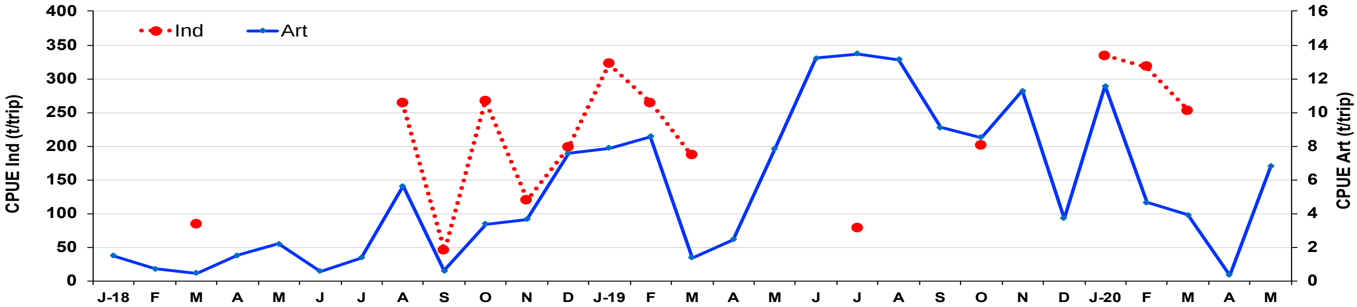


Figure 14.- Monthly catch per unit of effort (CPUE, in tons per trip) of Jack mackerel (*Trachurus murphyi*) by the industrial purse seine fleet (red dots and broken lines) and by the artisanal purse seine fleet (blue dots and lines) fishing in Peruvian waters between January 2018 and May 2020

The months with no CPUE data for the industrial purse seine fleet are indicative of the months when the fishing season for Jack mackerel by this fleet has been closed as part of the conservation and management measures applied by the Peruvian Government. As opposed to the industrial purse-seine Jack mackerel fishery that may be subject to several seasonal closures throughout the year, the artisanal fleet is usually authorized to fish for Jack mackerel all year round. This artisanal fleet also fishes for other fishery resources which may or may not have seasonal closures.

The 2018-2020 increase in the abundance of Jack mackerel illustrated by the CPUE values of both fleets shown above is corroborated by the observations made during the regular hydroacoustic pelagic resources assessment surveys conducted by IMARPE during the same period. These surveys may not be as effective in recording Jack mackerel schools that are close to the surface and usually only cover areas within 60 to 100 nm distance from the coast, potentially missing important off-shore Jack mackerel concentrations. As during IMARPE's recent pelagic stock assessment survey that only covered the first 90 nm distance from the coast from 15 February and 29 March 2020, and the bulk of the industrial fleet catches during those two months were made well beyond the 90 nm distance from the coast. But, even so, the observations made during these surveys have also shown a significant increase in the Jack mackerel acoustic abundance indices in late 2018 and throughout 2019 and early 2020. And, in fact, the acoustic abundance indices observed since September 2018 have been similar or well above the maximums observed between 2010 and 2014 and are consistently higher than those estimated during 2015-2017. Additionally, the acoustic abundance index observed during the September-November 2019 acoustic survey was the highest since 2007.

4.2. Fishing areas

As monthly catches increased, during 2018 and the first semester of 2020 the distribution of the Jack mackerel fishing grounds of both the artisanal and the industrial purse-seine fleet also expanded off-shore, particularly off the central and southern part of the Peruvian coast (Figure 15). This was a major change with respect to what was observed

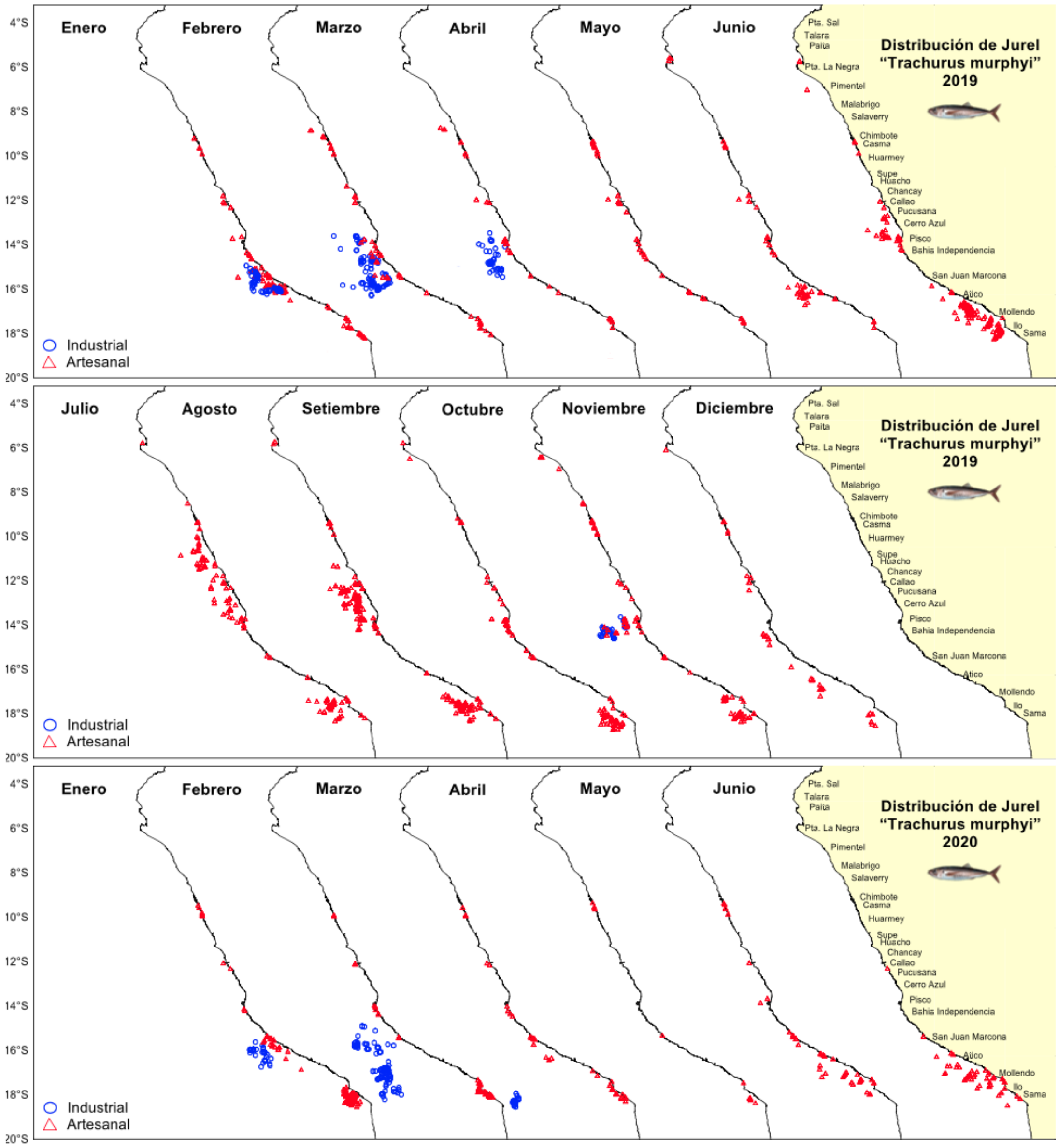


Figure 15.- Distribution of the Jack mackerel (*Trachurus murphyi*) fishing areas of the industrial purse seine fleet (blue circles) and by the artisanal fleet (red triangles) fishing in Peruvian jurisdictional waters, by month, between January 2019 to June 2020

during 2015, 2016 and 2017, when the fishing grounds for Jack mackerel were very close to the coast, mostly within 10 nm, as all the Jack mackerel fishing in those years was made by the artisanal and small-scale purse seine fleets.

During 2018 the fishing grounds of the artisanal and small-scale purse seine fleets continued to have a very coastal distribution, while the few catches of the industrial purse-seine fleet were made farther off-shore, mostly within 30 and 80 nm distance from the coast off Chicama-Chimbote in March-May, Atico-Morro Sama in August, Supe-Huacho in October, and off Callao-Pisco in November 2018.

During 2019-2020 the main fishing areas of the industrial purse-seine fleet were located from 5-10 nm as far as 130 nm distance from the coast between Callao and Atico in January-March and October 2019 (this fleet had only two trips and a very low catch in July and didn't fish for Jack mackerel the during the other months of 2019); and further south, as far as 180 nm distance from the coast, with the highest catches between 90 and 150 nm, between Bahia Independencia and Morro Sama in January-March 2020 (this fleet didn't fish for Jack mackerel during April-June 2020).

During 2019-2020 the fishing grounds of the artisanal fleet were also more widely distributed along the whole Peruvian coast, from the coastline to as far as 80 nm distance from the coast, as in August 2019 between Callao and Bahia Independencia. In general, the main Jack mackerel fishing grounds of the artisanal fleet were located with 60 nm distance from the coast between Chimbote and Morro Sama.

4.3. Size structure

The monthly size frequency distributions of Jack mackerel observed in the Peruvian fisheries by all fleets between January 2019 and June 2020 (Figure 16) continue to show the fishery targets on a wide range of sizes of Jack mackerel, with unimodal or multimodal groups, and sizes ranging from 18 cm to 52 cm in total length (TL).

As in previous years, there was a consistent presence of juveniles, with fish smaller than 31.0 cm TL throughout most of this period. However, as opposed to what was observed during 2018 when there was a prevalence of juveniles throughout most of the year, most of the catches during 2019 and 2020 were of adult Jack mackerels, larger than 31.0 cm TL. Except for April and May 2019 when juveniles represented 69.34% and 29.67% of the monthly catch in numbers, the proportion of juveniles throughout most of 2019 and 2020 has been well under 20% in numbers.

The monthly size-frequency distribution of Jack mackerel caught in Peruvian waters by all fleets between January 2019 and June 2020 is shown in Figure 16. These are presented in percentage. Due to the higher weight of the industrial purse seine fleet in the catch totals, the percentages are strongly influenced by the catches of this fleet in the months when this fleet has been fishing for Jack mackerel. However, this only occurred in January-March and October 2019 and in January-March 2020. The size-frequency distributions of all the other months are those of the artisanal fleet only.

On the overall, the size range observed in the fishery included fish from 18 to 52 cm TL, but there were two main size groups that were more clearly visible throughout the observed period from January 2019 to June 2020: one made up of adults with modal sizes between 35 and 36 cm LT that made the core of the high catches of Jack mackerel during January-March 2019; and another one that appeared as a new cohort in March and particularly in April 2019 with modal size in 29 cm LT, which was the main component

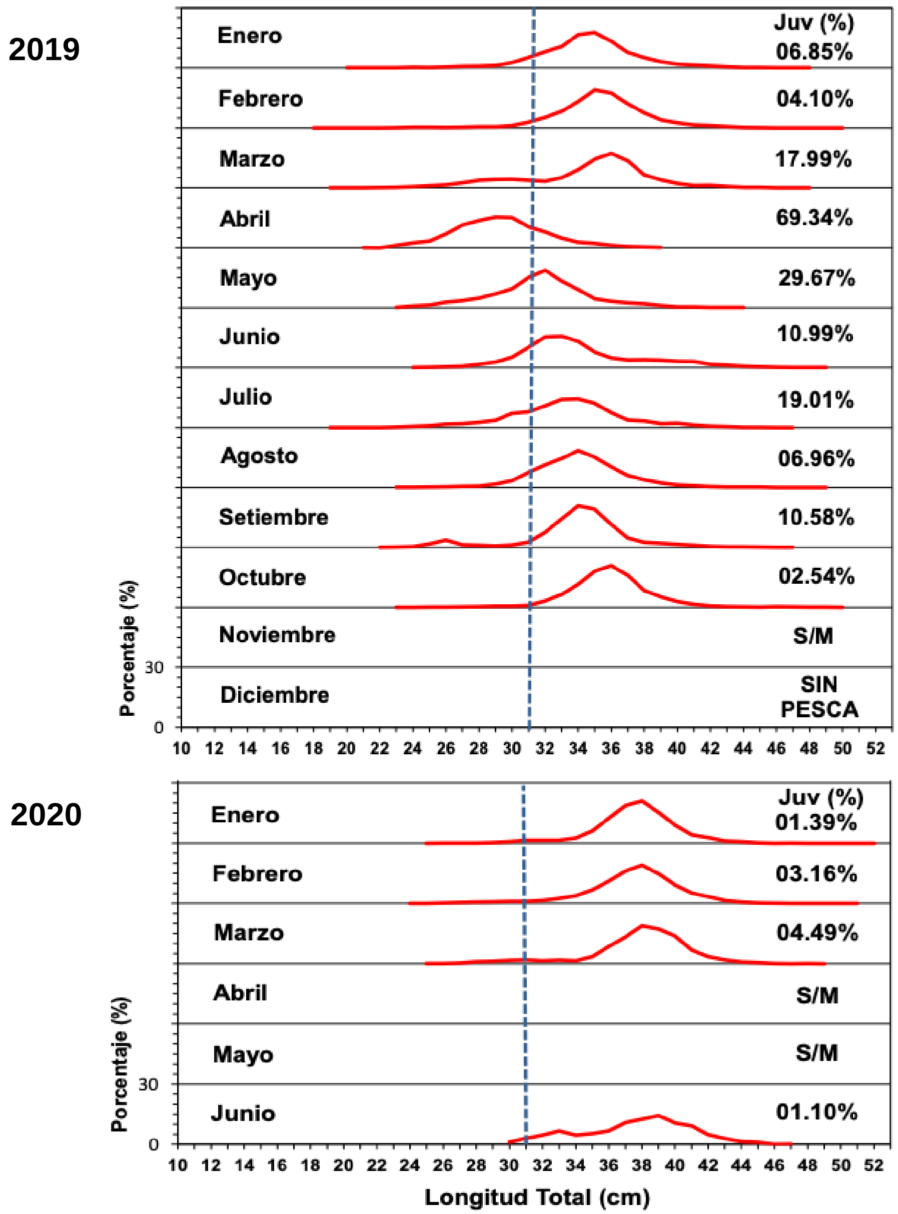


Figure 16.- Size frequency distribution of Jack mackerel (*Trachurus murphyi*) caught in Peruvian jurisdictional waters by the Peruvian artisanal and industrial fleets, by month, between January 2019 and June 2020

of the catches during the rest of 2019 and the first six months of 2020, having modal sizes in 36 cm LT in October 2019 and 38 cm LT in March 2020. Other minor groups with small sizes not usually targeted by the commercial fishery can be observed throughout the year, particularly in September 2019 with a modal size in 26 cm TL and in June 2020 with a modal size in 33 cm TL.

It is noted that there was no great difference between the observed monthly size-frequency distributions of Jack mackerel caught by the artisanal fleet and those caught by the industrial fleet, even though their main fishing areas were different and quite far apart, as most of the artisanal catches were made close to the coast and the catches of the industrial fleet usually farther off-shore (Figure 15). The main differences were in February 2019, when in both cases the main modal size was in 35 cm TL but in the artisanal catches the fish in the 20-28 cm TL range were slightly more abundant than in

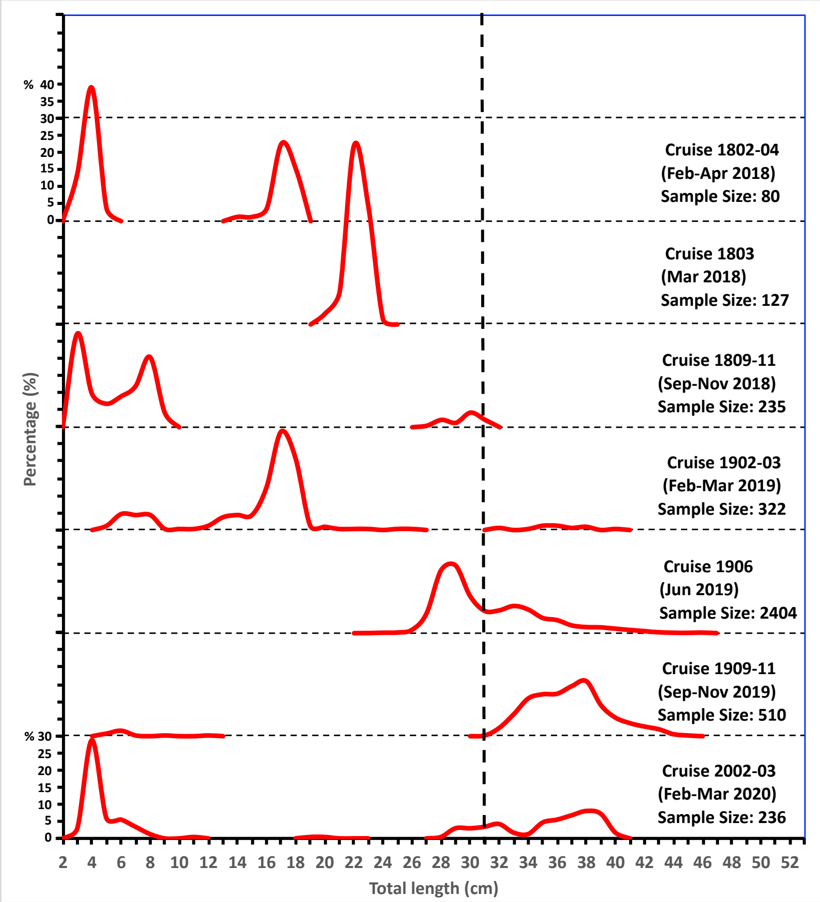


Figure 17.- Size-frequency distribution of Jack mackerel (*Trachurus murphyi*) caught in Peruvian jurisdictional waters during research surveys conducted by IMARPE between February 2018 and March 2020

the industrial catches; in March 2019, when most of the Jack mackerel caught by the industrial fleet were larger than 31 cm TL with a main modal size in 36 cm TL, most of the catches of the artisanal fleet was of fish smaller than 31 cm TL, with a main modal size in 29 cm TL; and, in January-March 2020, when as in February 2019 both fleets mainly caught large fish with a main modal size 38 cm TL, there was also a noticeable incidence of smaller fish in the range of 20 to 34 cm TL in the artisanal catches.

The recent research surveys conducted by IMARPE have also found the large-size modal groups that were caught by the commercial fleets during the regular commercial fishing seasons in 2018, 2019 and 2020 and, in addition, since the research vessels use different fishing gears with smaller mesh sizes, they also found much younger and smaller juveniles with total lengths as small as 3 cm (Figure 17). Fish that small don't show up at all in the commercial fishery that uses more selective nets with a minimum mesh size of 35 mm.

It is worth noting the range of large and small Jack mackerels sampled on board IMARPE research vessels, including those from 3 to 18 cm TL with modes in 4 and 17 cm TL caught in February-April 2018, as well as from 20 to 24 cm TL with modal size in 22 cm TL in March 2018; from 3 to 31 cm TL with modes in 3, 8 and 30 cm TL in September-November 2018; from 5 to 40 cm TL with modes in 6, 17 and 36 cm TL in February-March 2019; from 23 to 46 cm TL with modes in 29 and 33 cm TL in June 2019; from 5 to 45 cm TL with modes in 6, 34 and 38 cm TL in September-November 2019; and from 3 to 40 cm TL with modes in 4, 7, 29, 32 and 39 cm TL in February-March 2020.

Although the sample sizes are relatively small, particularly if compared with those from the commercial fishery, these fishery-independent length-frequency distributions from samples taken by IMARPE research vessels still provide a valuable indication of the presence of several cohorts of early juveniles and pre-recruits, not yet available to the commercial fishery but soon to be recruited to the exploited stock.

This also reinforces the observation made by Csirke & Ñiquen (2017) on the consistent occurrence of all life-history stages of Jack mackerel in Peruvian waters and that the Peruvian Jack mackerel stock reproduces itself and most likely completes its full life-cycle entirely in Peruvian waters.

5. STOCK ASSESSMENT

This section provides a brief summary of the late 2019 assessment of the Peruvian stock of Jack mackerel (far-north stock) which was used by the Peruvian Government to set the Jack mackerel total allowable catch (TAC) in Peruvian national jurisdictional waters for 2020. This is followed by a 2020 review and update with the Joint Jack Mackerel (JJM) model made by IMARPE using the most recent data and information with presumed catches projected to the end of 2020.

5.1. 2019 assessment and 2020 TAC

In late December 2019 IMARPE updated the available 2019 Jack mackerel assessment in order to advise the Vice-Ministry of Fisheries of the Ministry of Production (Ministerio de la Producción, PRODUCE) on the most current situation of the stock and the possible TAC for 2020 (IMARPE 2019). This assessment was based on the latest version of the JJM model developed during the 7th Meeting of the Scientific Committee held in La Havana, Cuba, in October 2019 (SPRFMO 2019), with all data and information updated to December 2019.

The stock size estimated on January 1st 2020 was projected to the end of the year under several exploitation scenarios, each one related to a TAC and to relative adjustments of the fishing effort and/or the fishing mortality (F). For each case, the fishing mortality to be applied was estimated considering the risk that the biomass estimated at January 1st 2021 be lower than that estimated for January 1st 2020. Based on this a range of options was chosen considering those for which there was a high enough probability that the spawning biomass will continue to be greater than that needed for the Maximum Sustainable Yield (MSY) in the short, medium and long terms; that the ratio between the current F and F_{MSY} required for the MSY remains below 1; and, the ratio between the spawning biomass for 2020 and that required for the MSY was greater than 1.

In addition to the results of the updated JJM model, in providing its late December 2019 advice to the Government on the prospects of the Peruvian Jack mackerel fishery for 2020, IMARPE also considered the most recent information it had access to on the prevailing environmental conditions and on the catch, distribution, abundance, size-frequency distribution, etc., of Jack mackerel in Peruvian waters. And took into consideration the possibility that during 2020 there could be unforeseen short-term environmentally-driven stock fluctuations under the effects of the El Niño Southern Oscillation (ENSO), changes in atmospheric circulation and the arrival of cold or warm Kelvin waves as frequently has been observed in the past.

Therefore, even if the observed environmental conditions were described as neutral or close to neutral by December 2019, there was a certain degree of uncertainty on how the environmental conditions during 2020 would be like. And this caused IMARPE's advice to be guided by a certain sense of cautiousness when deciding on a precautionary range of values of F and corresponding TACs to be included in its late December 2019 advice to the Government, with values well under the estimated F_{MSY} and corresponding MSY.

This produced a range of acceptable options and IMARPE's recommendation was that a TAC for 2020 be established considering a multiplier of F_{2019} not exceeding 2.0 that corresponded to a maximum estimated F = 0.0652 and a maximum projected TAC = 140 000 t, accepting a risk of 30.9% that the estimated biomass by January 1st 2021 be lower than that estimated for January 1st 2020.

The IMARPE advice also stated its concerns regarding the effects of possible short-term changing environmental conditions and indicated that the above values could be readjusted in the course of the year if the results of follow-up research surveys and the regular monitoring of the environmental conditions and of the state of the stock and the fishery showed that there was a greater availability of Jack mackerel and generally more favorable conditions than those observed or estimated by late December 2019.

Based on this advice, on 17 January 2020 PRODUCE established a catch limit of 100 000 t for Jack mackerel (*Trachurus murphyi*) to be caught in Peruvian jurisdictional waters during 2020, of which 70 000 t were allocated to the industrial fleet and 30 000 t to the artisanal fleet. The above TAC = 100 000 t corresponded to a multiplier of F_{2019} = 1.39 and an estimated F_{2020} = 0.0455, lower than the maximum in IMARPE's December 2019 advice. PRODUCE's resolution also indicated that the above TAC could be modified depending on the biological and/or environmental factors, including evidences about the state of the stock that may be provided by IMARPE.

5.1.1. Revised 2019 assessment and 2020 TAC

Most of the uncertainties regarding the short-term environmental conditions and the possible changes in distribution, abundance, etc., of the Jack mackerel stock that guided the cautious approach in IMARPE's late December 2019 advice and in PRODUCE's mid-January decision about the 2020 TAC were dissipated by the slightly warm but close to neutral marine environmental conditions and the ample distribution and relatively high abundance indexes of Jack mackerel in Peruvian waters observed during the first three months of 2020. This allowed for a more favorable and reassuring overall assessment of the environmental and stock conditions, but since the new information mostly confirmed what was expected, IMARPE just noted this more reassuring short-term situation and ratified its initial advice of limiting F during 2020 to a level that would produce a TAC = 140 000 t as a maximum.

At the same time, the industrial purse seine fleet had a very successful start of the 2020 Jack mackerel fishing season and managed to catch most of its yearly allocated Jack mackerel quota within the first two months of the year, the Government declared the State of Emergency due to the COVID-19 outbreak and, besides the public health issues that became of main national concern, there was a general awareness of the need to guarantee the food supply to national markets. This would include the supply of fish and fish products for local consumption, of which Jack mackerel is much appreciated and a highly demand source of animal protein by medium to low income families.

All these circumstances lead PRODUCE to, with effect as of 26 March 2020, increase the 2020 Jack mackerel TAC to the maximum of 140 000 t in IMARPE's original advice, limit further Jack mackerel catches to those made by the artisanal fleet, and maintain the industrial purse seine Jack mackerel fishing season closed until further notice.

5.2. 2020 assessment

The main purpose of this latest 2020 assessment is to update the JJM model estimates with the most recent data and information up to June 2020, but with estimated total catch projected to December 2020, using the same configurations of the JJM of 2019 model developed during the 7th meeting of the Scientific Committee in October 2019 and used in IMARPE's late December 2019 advice.

5.2.1. Updated information used in the 2020 assessment

Information about catch, catch at length, catch at age and weight at age were updated to June 2020, with estimated total catch projected to December 2020. The *echo-abundance,* selectivity and the remaining biological data (sexual maturity, age and growth and M) were maintained to be unchanged with respect to the 2014 model since either the new information confirmed the validity of the parameters being used or there was no new estimate or data to be added.

The IMARPE´s Fisheries Monitoring System routinely collects catch and length composition data. Year length-frequency distributions were converted to ages using the age and growth parameters estimated by Dioses (2013). The revised CPUE abundance index based on the industrial and the artisanal and small-scale catch and effort data and a Generalized Additive Model used in 2019 was updated, but now for the period 2002-2020 (Figure 18).

It is noted that the updated 2020 CPUE (updated to May 2020 only) is much lower than the 2019 CPUE, although it is a bit higher when the comparison is made with the 2019 CPUE updated to June 2019. This is due to the effect of the higher CPUE of the industrial fleet during the first 3 months of 2020 and the high CPUE of the artisanal and small-scale

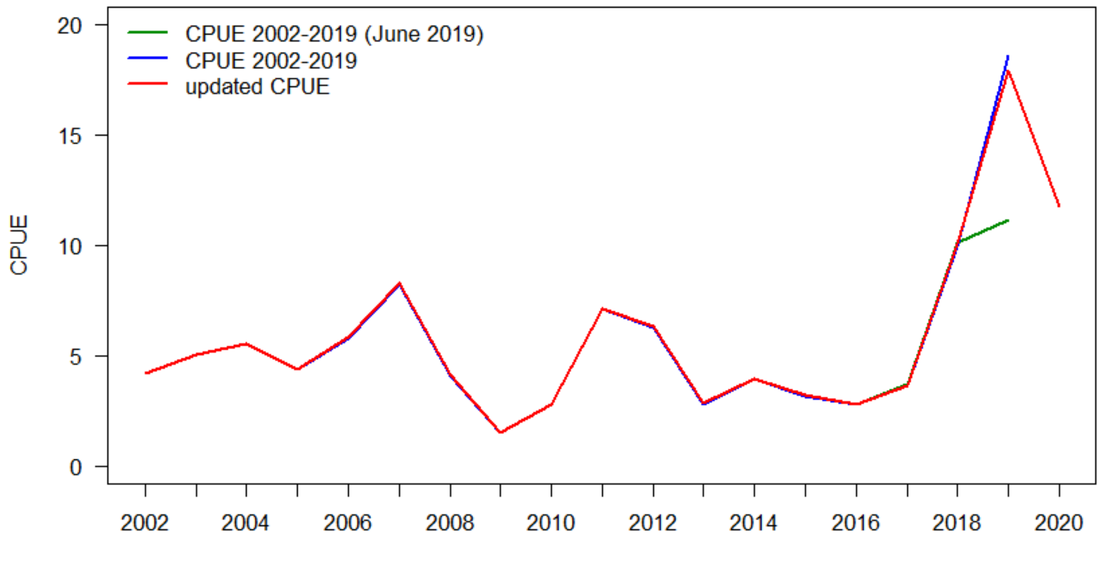


Figure 18.- Updated CPUE time series of Jack mackerel *Trachurus murphyi* caught in Peruvian jurisdictional waters by the industrial and the artisanal and small-scale fleets between 2002 and 2020

fleets between June and December 2019 (Figure 14), which are months not yet represented in the 2020 CPUE update.

As mentioned in previous reports, the *echo-abundance* index used in the assessment was estimated as the mean value of all the Nautical Area Backscattering Coefficients (S_A) recorded during the acoustic surveys conducted by IMARPE since 1985. The use of the S_A coefficient is preferred to the acoustic biomass estimates in order to reduce potential sources of bias that might be introduced by using length frequency data collected during the acoustic surveys to estimate fish density in numbers (abundance) and weight (biomass).

The current record of echo-abundance of Jack mackerel only provides estimates up to 2014, because the environmental conditions typical of the strong El Niño in 2015-2016 and the moderate coastal El Niño in late 2016 and early 2017 caused the anchoveta to be distributed very close to the coast, and, therefore, the acoustic surveys that are primarily designed to survey the anchoveta stock were designed to cover areas much closer to the coast (less than 60 nm distance from the coastline) where there is a reduced probability of finding the best concentrations of Jack mackerel.

Then, the pelagic stock assessment acoustic survey conducted in early 2018 had a wider offshore coverage (from 5 to 100 nm distance from the coastline) but it is expected that the coastal cooling and stronger upwelling associated with the weak-to-moderate La Niña in late 2017 to early 2018 would have dispersed farther offshore any good concentrations of Jack mackerel. And the pelagic stock assessment research surveys conducted in May-June 2019 and February-March 2020 also covered an undetermined fraction of the total distribution of Jack mackerel in Peruvian waters, and, therefore, were also not incorporated in the current 2020 JJM assessments.

In fact, as mentioned in sections 4.1. and 4.2. above, the most recent IMARPE pelagic stock assessment survey conducted between 15 February and 29 March 2020 covered an area that extended as far as 90 nm from the coast, where it found relatively few spots with Jack mackerel concentrations (mostly off Paita and Salaverry in the north and off San Juan and Atico in the south). While during those two months all the Jack mackerel caught by the artisanal fleet came from numerous very coastal areas from Chimbote in the north to Morro Sama in the south, almost all the catches by the industrial purse seine fleet were made in off-shore areas well beyond the 90 nm distance from the coast between Bahia Independencia and Morro Sama (Figure 15).

Jack mackerel caught by the artisanal fleet came from numerous very coastal areas from Chimbote in the north to Morro Sama in the south, and almost all the catches by the industrial purse seine fleet were made in farther off-shore areas, well beyond the 90 nm distance from the coast between Bahia Independencia and Morro Sama (Figure 15).

The biological data, including sexual maturity at age was estimated from a length-based ogive using the information from Perea *et al.* (2013) and Dioses (2013a). The weight at age matrix was estimated from the mid length at age, age and growth parameters and the length-weight relationship parameters estimated by year.

A summary of the fishery dependent, fishery independent and biological data used is given in Table 1.

Table 1.- Data used in the 2020 assessment of the Peruvian (far-north) Jack mackerel

Type	Data	Details
From the fishery	Catch Catch-at-length Catch-at-age CPUE Selectivity	1970 – 2020 1980 – 2020 1980 – 2020 2002 – 2020 Dome shaped
Fishery independent	Echo-abundance Selectivity	1985 – 2014 Logistic
Biological	Growth parameters Natural mortality Maturity at age Weight at age	k=0.165 y^{-1}, L_{∞}=80.4cm M=0.33 First mat=2 y From updated W-L parameters

5.2.2. 2020 Joint Jack Mackerel (JJM) model

The same configurations of the 2019 assessment were implemented in the 2020 assessment with the JJM model, trying to achieve the best representation of the population dynamics of the Peruvian (far-north) stock.

The configurations used are presented in Table 2 below.

Table 2.- Model configurations implemented in the 2020 JJM assessment of the Peruvian (far-north) Jack mackerel stock

Model	Description
Data update	
0.0	- As 2019 configuration and data - Indices: *echo-abundance* (cv=0.2) and CPUE (cv=0.2) - Stock-recruitment relationship: recruits from 1970 to 2018 to scale, with two regimes
0.1	As in model 0.0 but with updated catch and length composition to 2020
0.2	As in model 0.1 but with updated CPUE (2002-2020)
0.3	As in model 0.2 but with updated mean weight at age
Model configuration	
1.0	As in model 0.3 (steepness = 0.6)
1.1	As in model 1.0 but steepness = 0.8
1.2	As in model 1.0 but stock-recruitment relationship: recruit from 1970 to 2019 to scale with two regimes

The addition of updated information, either catches, length compositions, CPUE or mean weight at age (group 0 models), did not result in a substantial change in the overall trend of the total biomass, being almost the same. Configurations 0.0 and 0.1 produced slightly higher values of biomass at the beginning of the series but similar values of biomass at the end of the series (Figure 19a).

The group 1 models were used to analyze the sensibility of the recruitment parameters, through the *steepness*. The trends in biomass (Figure 19c) were very similar in those configurations, also with configurations 1.1 and 1.2 producing slightly higher values of biomass at the beginning of the series but similar values of biomass at the end of the series (Figure 19d).

Two periods, or regimes, with marked contrast of productivity were still observed with group 0 and group 1 models. The first period of higher biomass during the 1980s and 1990s, and the second one with lower biomass since 2000. These two regimes described by the JJM model are consistent with the observed decadal regime changes in the marine

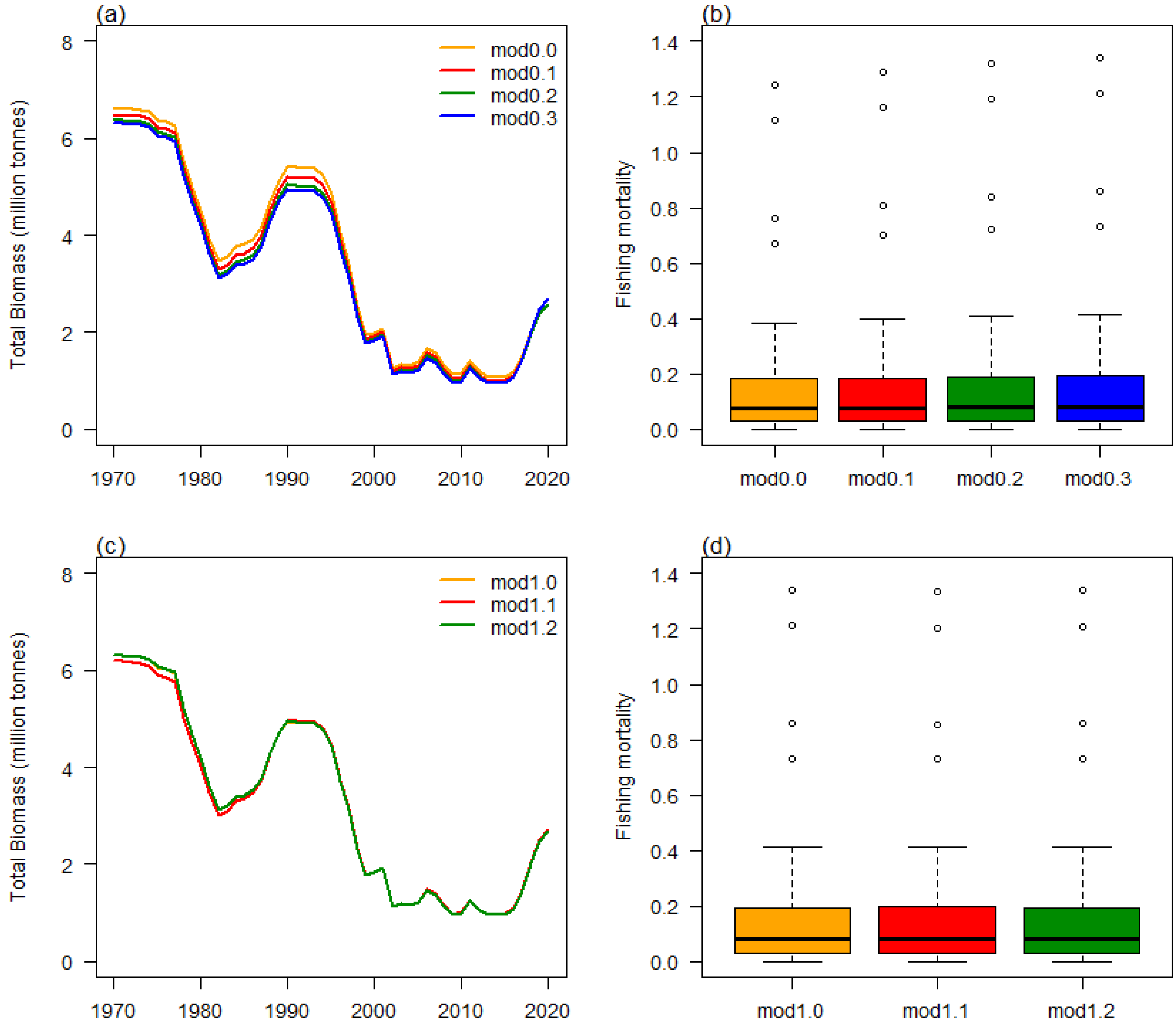


Figure 19.- Main outputs for the group 0 (top panel - testing the sensitivity to updated data) and group 1 (bottom panel - testing the sensitivity to assumptions on recruitment productivity) model configurations of the 2020 assessment with the Joint Jack Mackerel (JJM) model: (a) total biomass series (in million t) by year for group 0 models; (b) yearly fishing mortality distribution estimated for group 0 models ; (c) total biomass series (in million t) by year for group 1 models; and, (d) yearly fishing mortality distribution estimated for group 1 models

environment and in the distribution, abundance population structure and other biological characteristics of various marine species, including Jack mackerel, in the Peruvian marine ecosystem described by several authors (*e.g.*: Jordan 1983, Chavez *et al.* 2003, 2008, Csirke 2013, Csirke *et al.* 2013, 2018, Arguelles *et al.* 2019).

The mean value of fishing mortality estimated for years between 1970 and 2020 was very similar for the seven configurations, as well as their distributions (Figures 19b and 19d).

The outputs of the final configuration show a slight increase in the biomass of 2020 with respect to the biomass of 2019 and, in general, a growing trend of this variable since 2016.

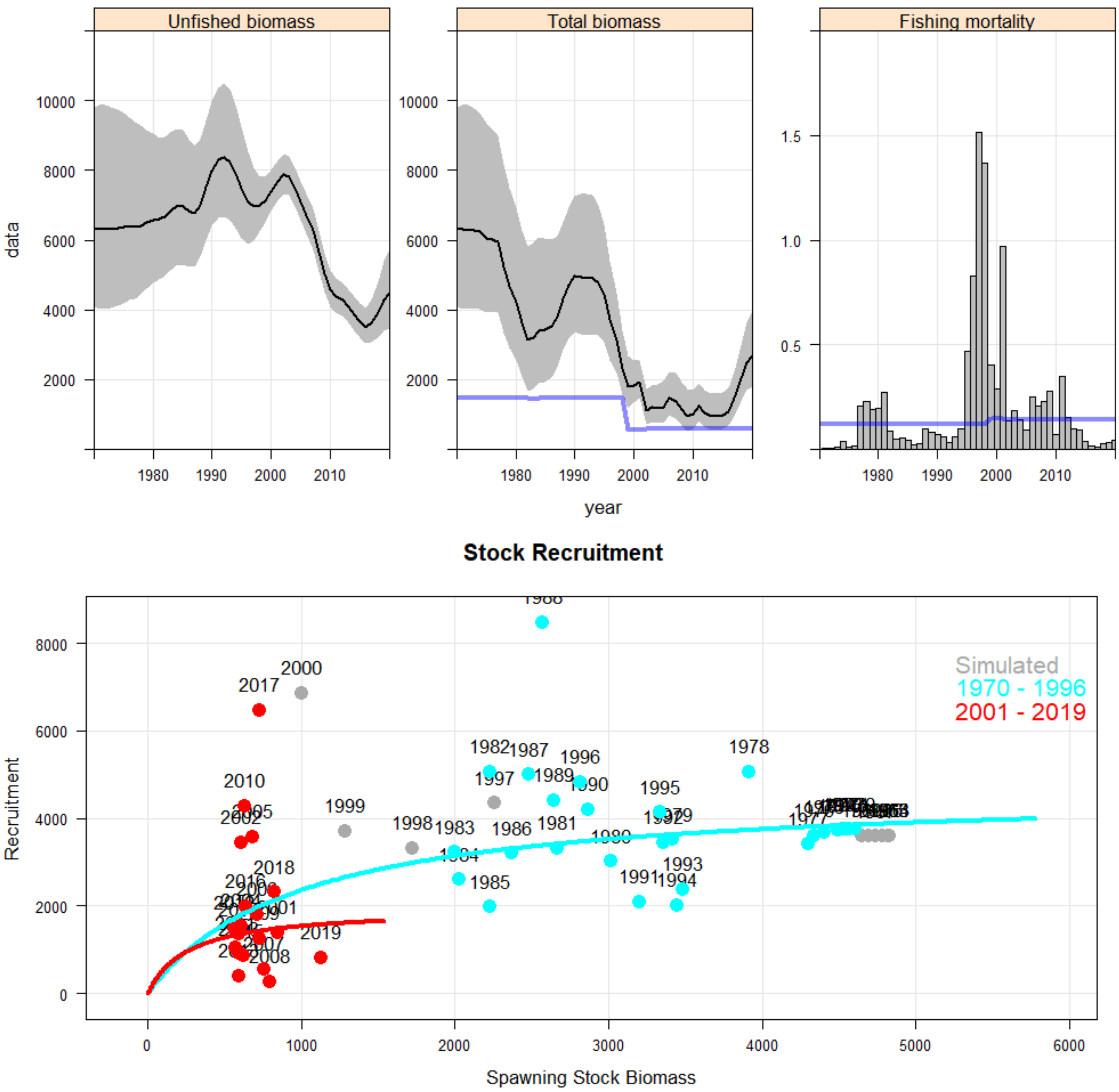


Figure 20.- Outputs of the final configuration of the JJM model showing the history and current situation of the Peruvian (far-north) stock of Jack mackerel (*Trachurus murphyi*). Unfished biomass and total biomass (in thousand t) and yearly fishing mortality are presented at the top panels. The stock-recruitment relationship showing two regimes is presented in the lower panel. The horizontal blue lines in the two top-right panels represent the estimated reference levels of mean total biomass (B_{MSY}) and annual fishing mortality (F_{MSY}) corresponding to the Maximum Sustainable Yield (MSY).

The history and current situation of the unfished biomass, total biomass and annual fishing mortality of the Peruvian (far-north) stock as estimated with the JJM model are presented in the top three panels in Figure 20 and those of the spawning stock and resulting recruitment are presented in the lower panel in the same figure.

As can be noted, the stock would have passed through two stages of productivity, or regimes, with high levels of total biomass during the 1990s and low levels at present. These two stages have been represented by two stock-recruitment regimes (Figure 20, lower panel). With one high productivity regime from 1970 to 1996 and a lower productivity regime from 2001 to 2019. The period 1997-2000 was not considered in the fitting of the two stock-recruitment curves due to the high variability observed for those years, which apparently was mainly induced by the very strong 1997-1998 El Niño and probable instability caused by the regime change itself.

It is noted that the outputs obtained with the final configuration of the JJM model used, as well the eventual forward projections under various scenarios of F, indicate that the total biomass as well as the spawning stock biomass are well above the levels required for the MSY under the current low abundance regime. This plus the low future recruitments that are predicted by the JJM model based on the stock-recruitment relationship mean curve for the low abundance regime (Figure 20) and the relatively low incidence of juveniles in the commercial catches during 2019 and 2020 (Figure 16) cause the biomass projections to flatten out with projected values of fishing mortality close to F = 0 and to bend downwards even with slight increases of F. This suggests that according to the JJM model the stock may be at or close to its maximum level given the low abundance regime in which it presumably has been since 2001. The estimates and projections of biomass and other variables obtained with the JJM also show the greater variability of past recruitments and the great uncertainty about the intensity of future recruitments, reflecting quite well what has been observed and is partially described in sections above with respect to environmental variability and its effects on the behavior, distribution, abundance, etc., of Jack mackerel in Peruvian waters.

6. REFERENCES

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