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INSTITUTO DEL MAR DEL PERU
IMARPE

MINISTERIO DE LA PRODUCCION
PRODUCE

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Peru National Report N° 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 2018 – JUNE 2019

by

IMARPE - PRODUCE

2019

SUMMARY

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. Which 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; while the slightly warmer than neutral conditions associated with the weak 2018-2019 El Niño favored the presence 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 and first half of 2019. Jack mackerel abundance indexes from scientific surveys and from the fishery increased noticeably between January 2018 and August 2019, and composite yearly CPUE values of 2018 and 2019 were well above the CPUE values observed between 2002 and 2017. In early January 2018 IMARPE updated the available 2018 Jack mackerel assessment made for the Peruvian (far-north) stock during the SC-06 and estimated a TAC for 2019 of 79 000 t, with an $F_{2019} = 0.032$ and an estimated risk of 17.5% that the biomass projected to January 1st 2020 be lower than that estimated for January 2019. A readjustment of the estimated TAC, by an additional 20 000 t, bringing the revised TAC to 99000 t for the whole year was made by the end of March 2019 based on an updated assessment of the situation on the basis of the newer information and data collected during January, February and March 2019. The main results of an updated 2019 assessment using Information about catch, catch at length, and catch at age updated to June 2019 is also presented.

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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; Csirke *et al.* 2013).

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. These abnormal 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, contributed to a noticeable increase in both, the abundance indexes and the monthly catches of Jack mackerel during the second half 2018 and first half of 2019.

2. THE MARINE ENVIRONMENT

A weak El Niño developed off the Peruvian coast during 2014 and after a short period of close to normal environmental conditions a strong El Niño developed, lasting from April 2015 to April 2016. After a short period of warm but close to neutral conditions an unexpected warming, described as a moderate-coastal El Niño, followed 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 normal conditions developing into a weak El Niño from late December 2018 to March 2019, with close to neutral conditions between April and June 2019.

The extent and intensity of this sequence of events, the difference between the more regional weak 2014 and strong 2015-2016 El Niños, the moderate coastal 2017 El Niño, the more regional weak-to-moderate 2017-2018 La Niña and the recent weak 2018-2019 El Niño are described by the monthly thermal anomalies (°C) based on the Coastal Index of El Niño (ICEN) in the Niño 1+2 region (Figure 1), and the equivalent but more coastal LABCOS index of the sea surface temperature anomalies along the Peruvian coast, developed by the "Instituto del Mar del Perú" (IMARPE) on the basis of the sea surface temperature records from by its own network of coastal laboratories and marine stations (Figures 2 and 3).

As can be noted from the two indices in Figures 1 and 2, the 2014 El Niño was a weak one, while the 2015-16 El Niño described as a strong one Impacted the whole Peruvian coast, but its strongest effects were felt north of Callao (12°S). It was, however, not as strong and didn't had 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 the moderate 2017 coastal El Niño were lessened, and soon after upturned, by the cooling influence of the weak-to-moderate 2017-2018 La Niña. Which was followed by the weak 2018-2019 El Niño
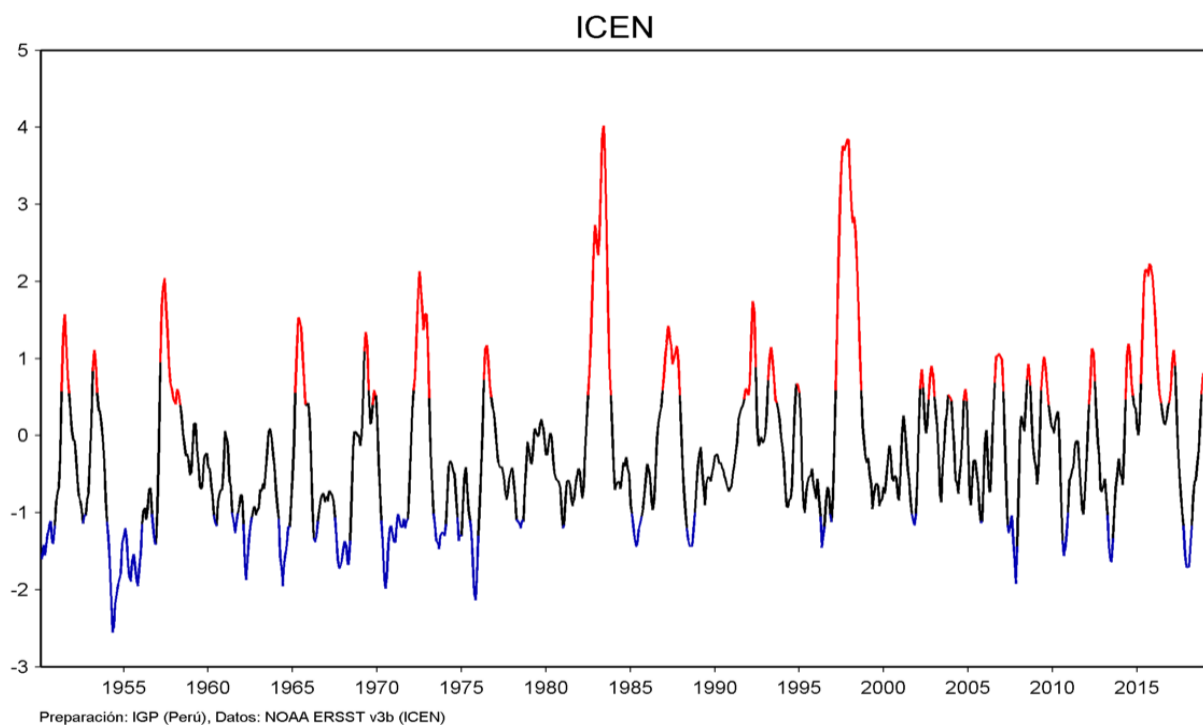
Figure 1.- Coastal Index of El Niño (ICEN) in the El Niño 1+2 region, by month, from January 1950 to June 2019. Calculated as the 3-month moving average of the anomalies of the sea surface temperature in the Niño 1+2 region, referred to a 30-year (1981-2010) monthly mean pattern. Warm El Niño conditions are highlighted in red and cold La Niña conditions are highlighted in blue (data source: IGP, NOAA ERSST-ICEN)
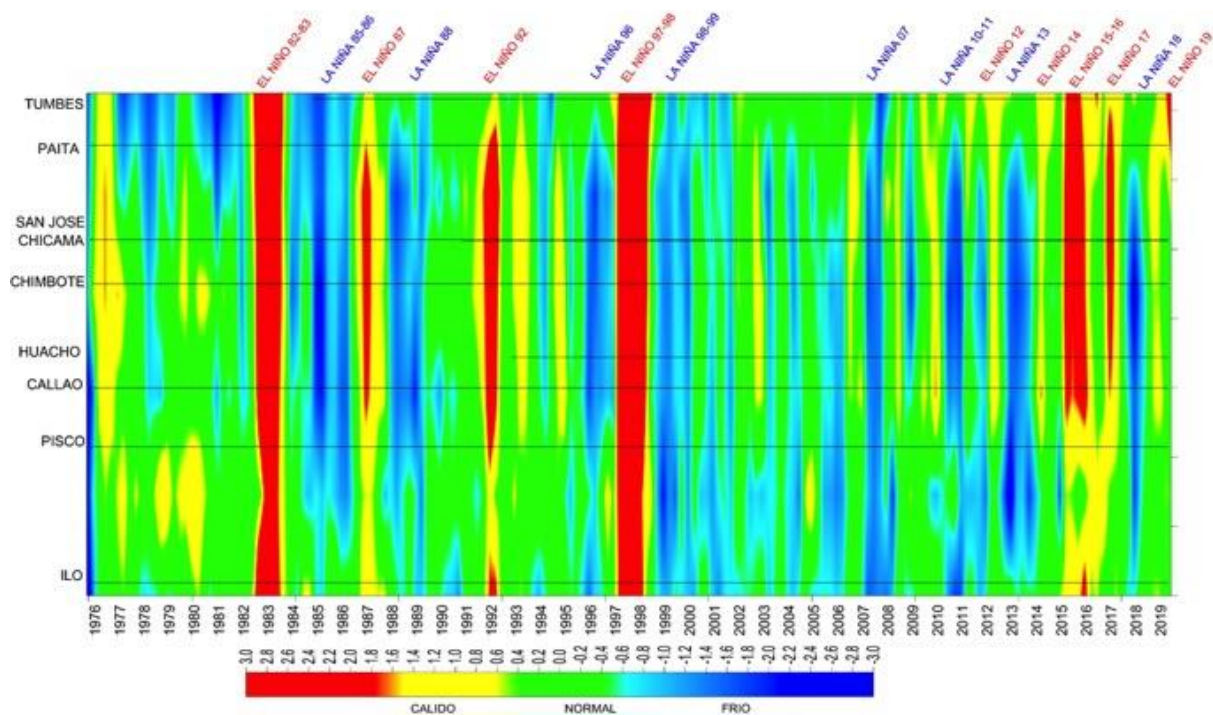
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Figure 2.- LABCOS index of the sea surface temperature anomalies from IMARPE´s coastal laboratories and stations, by latitude along the entire Peruvian coast, years 1976–2010 (until May 2019) (source: IMARPE)

During the strong 2015-2016 El Niño, the average monthly sea surface temperature anomaly (SSTA) in the Niño 1+2 region (ICEN index) was positive (warmer) and noticeably higher since April 2015, remaining consistently above +0.5°C throughout May 2016, with a maximum of +2.2°C in October 2015 and values above +1.0 throughout March 2016. The anomalies then weakened rapidly, tending to stabilize at positive, yet closer to neutral values (at or below +0.4°C) until December 2016.

The ICEN index for the Niño 1+2 region then increased again during the development of the moderate 2017 coastal El Niño, reaching a maximum monthly anomaly of +1.1°C in March 2017, to decline to +0.4°C in May 2017 and flip to negative anomalies of -0.8°C in August 2017, -1.5°C in November and maximum negative values of -1.7°C in December 2017 and January-February 2018. Turning into what has been defined as a weak-to-moderate 2017-2018 La Niña. Which, soon after developed into a weak 2018-2019 El Niño, with positive anomalies over +0.5°C from November 2018 throughout January 2019, and peak anomaly of +0.81°C in December 2018.

During the same period, the more coastal LABCOS index, based on IMARPE's records from its own coastal laboratories and marine stations, describes the more coastal evolution of these last three El Niños and one La Niña, as shown in Figure 3.

It has been noted that the evolution of the SSTA along the more coastal marine areas off Perú has been slightly different than in the Niño 1+2 region, particularly during the moderate 2017 coastal El Niño. In fact, the observed positive SSTAs during the moderate 2017 coastal El Niño were much lower than those during the strong 2015-2016 El Niño in the Niño 1+2 region, according to the ICEN index. Whereas SSTAs along the Peruvian coast where almost as high in both El Niño, as indicated by the coastal LABCOS index.

As in the Niño 1+2 region, positive SSTA values during the strong 2015-2016 El Niño were also noticeably high through the coastal LABCOS index since May 2015, reaching a maximum 3-month moving average of +2.3°C centered in June 2015, to decline to +1.5°C in August 2015 and increase again, peaking at +1.9°C in December 2015. The LABCOS SSTA values then declined as the strong 2015-2016 El Niño faded away, with more neutral values below +0.5°C from June throughout December 2016, to then increase again with the development of the moderate-coastal El Niño in
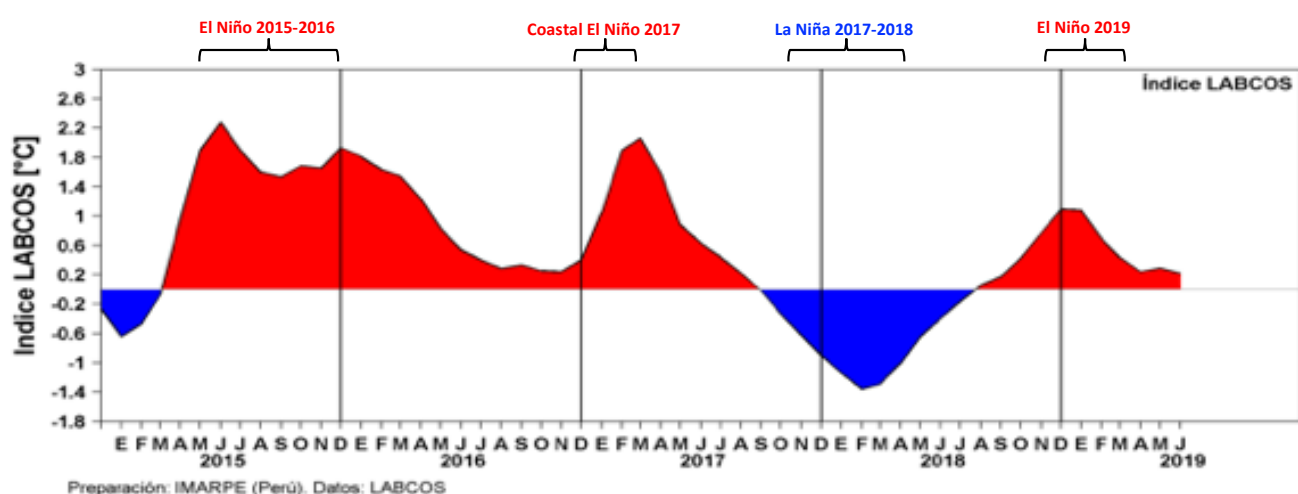

Figure 3.- Fluctuations in the monthly sea surface temperature anomalies (SSTA, in °C) along the Peruvian coastline as reflected by the 3-month moving average of IMARPE's LABCOS index (Quispe & Vásquez 2015), from January 2015 to June 2019

January 2017, reaching a maximum 3-month moving average of +2.0°C in March 2017 and declining to +0.8°C through May 2017.

The cooling continued, reaching neutral conditions by September 2017 and continued to cool while developing into the weak-to-moderate 2017-2018 La Niña, with the LABCOS index flipping into negative anomalies of -0.4°C in October 2017, -0.9°C in December 2017, and the maximum negative anomalies of -1.4°C in February 2018, and -1.3°C in March 2018, during the full development of the weak-to-moderate 2017-2018 La Niña. By May 2018 the negative anomaly was reduced to -0.7°C, and to -0.2°C by July 2018, to then start warming up to develop into the weak 2018-2019 El Niño with a maximum positive LABCOS index of almost +1.1°C in December 2018 and January 2019. Since then, the LABCOS index has stabilized at +0.2°C between April and June 2019.

The extent of the changes in environmental conditions affecting the Peruvian coastal marine environment during the last three years is also illustrated by comparing the observed summer season distribution of the sea surface temperature (SST) and its anomalies (SSTA) along the Peruvian coast in March-April 2017 (during the full development of the moderate 2017 coastal El Niño), February-April 2018 (during the full development of the weak-to-moderate 2017-2018 La Niña) and February-March 2019 (during the declining phase of the weak 2018-2019 El Niño) in Figures 4, 5 and 6; and, also by comparison with the sea surface salinity (SSS) and its anomalies (SSSA) during the same three periods (Figures 7, 8 and 9).

As can be seen in Figure 4, in March-April 2017, during the full development of the moderate 2017 coastal El Niño, the SST off the Peruvian coast varied from 16.1 to 27.9°C, and SST values higher than 27°C were found as close as 30nm from the coast

Figure 4.- Distribution of the sea surface temperature (SST, in °C, left panel) and sea surface temperature anomalies (SSTA, in °C, right panel) during March-April 2017, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 1703-04, 3 March - 13 April 2017 (during the full development of the moderate 2017 coastal El Niño)

between Salaverry (8°13'S) and Casma (9°28'S). SST values lower than 20°C associated with upwelling processes were only found in coastal areas within 15 nm from the coast between Bahía Independencia (14°14'S) and Atico (16°13'S) and off Morro Sama (18°00'S). There was a predominance of warmer than normal conditions throughout most of the coast, with positive SSTAs of up to +6°C off Chimbote (09°04'S) and SSTAs higher than +3°C very close to the coast between 8°S and 11°S and between 13°S and 15°S, and within 60 nm and farther than 30 nm from the coast south of 15°S. With the only negative anomalies to the south of 16°S, were there was a coastal area with negative SSTAs as low as -2°C off Atico (16°13'S)
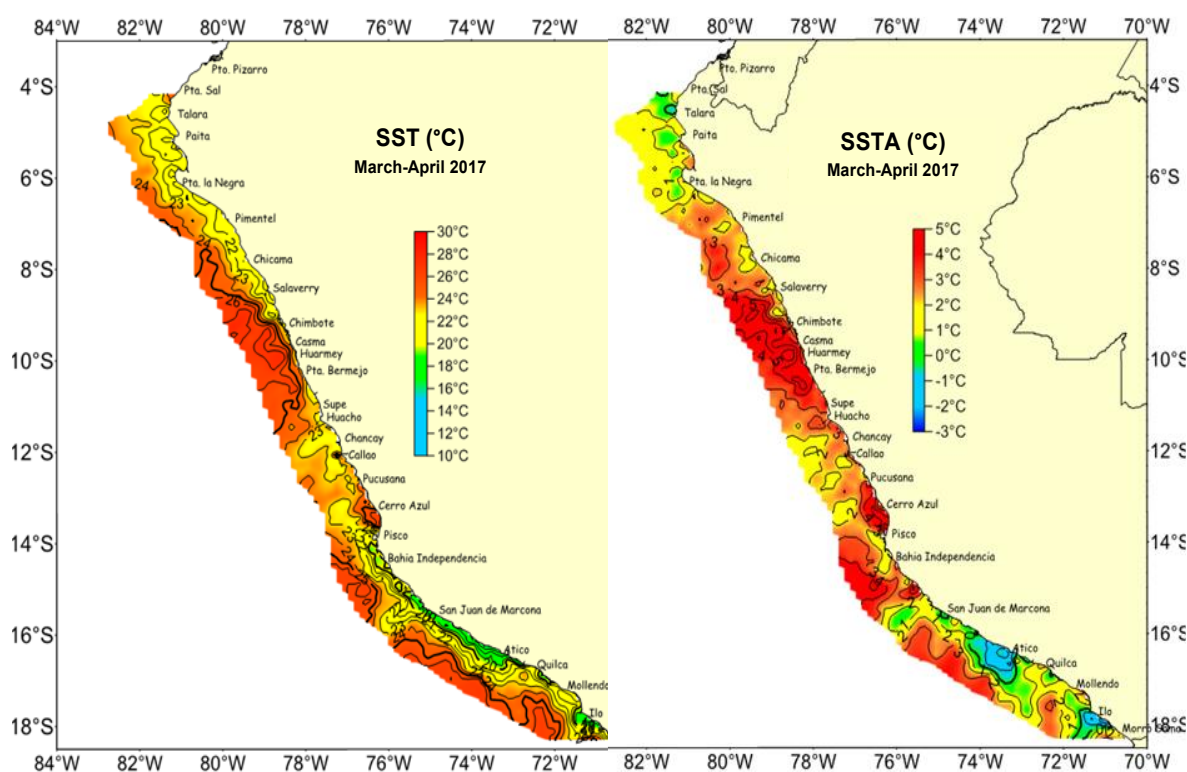
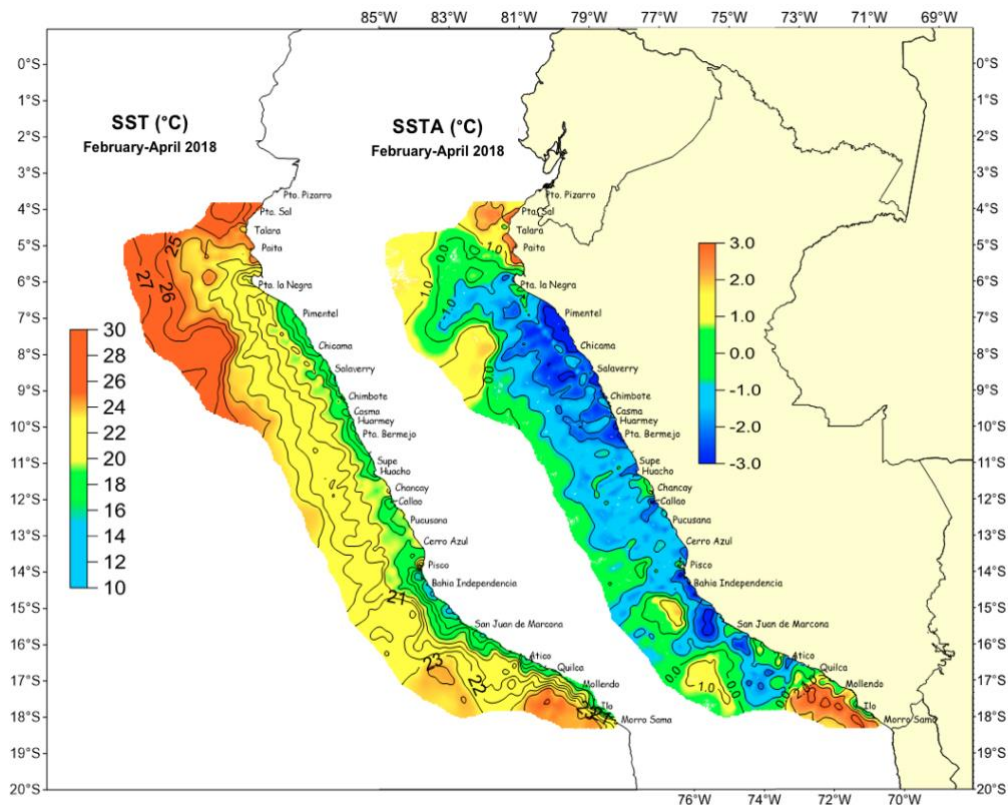**Figure 5.- Distribution of the sea surface temperature (SST, in °C, left panel) and sea surface temperature anomalies (SSTA, in °C, right panel) during February-April 2018, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 1802-04, 22 February - 6 April 2018 (during the full development of the weak-to-moderate 2017-2018 La Niña)**

Environmental conditions were much colder in February-April 2018 (Figure 5), during the weak-to-moderate 2017-2018 La Niña. SST values higher than 27°C were only found beyond 160 nm from the coast off Paita (5°05'S) and Chicama (7°55'S), while SST values lower than 20°C that are associated with upwelling processes extended along the coast as far as 20 nm and in many cases more than 60 nm from the coast from San José (6°45'S) to Morro Sama (18°00'S). There was a clear predominance of colder than normal conditions throughout most of the coast, with negative SSTA values of at least -1°C as far as 150 nm from Punta la Negra (6°00'S) in the north to Atico (16°13'S) in the south, with several pockets of negative SSTA of -3°C closer to the coast between Pimentel (6°50'S) and Salaverry (8°13'S), off Callao (12°00'S) and between Pisco (13°42'S) and San Juan de Marcona (15°21'S).

Slightly warmer than normal conditions were then observed in February-March 2019 (Figure 6), during the weak 2018-2019 El Niño. Observed SST values ranged from 16.8 to 27.5°C, with the highest values in the north, beyond 50 nm distance from the

coast off Punta Sal (06°00'S). The general thermal distribution was made up of nine isotherms (19° to 27°C) parallel to the coast. The coastal areas recorded the lowest temperatures, with SST fluctuating between 16.8°C and 19.0°C. Observed SSTA values varied between -4.2°C and + 4.0°C, with an average of +0.4°C, negative anomalies north of San Jose (6°45'S) and predominance of positive anomalies from Chicama (7°55'S) to Bahía Independencia (14°14'S) and negative anomalies further south.
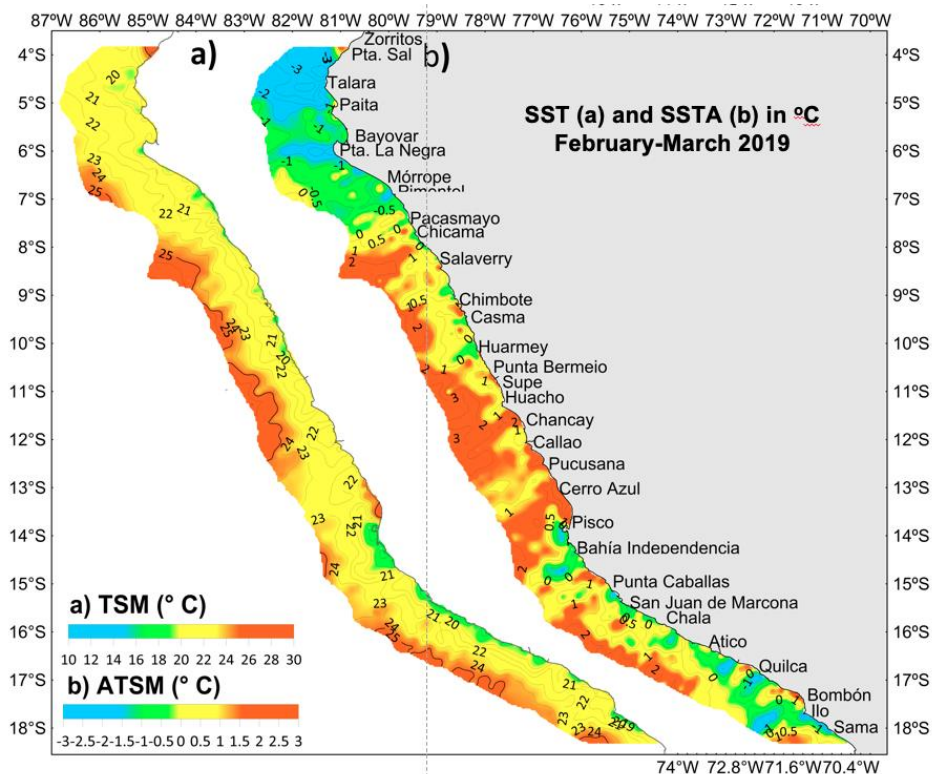

Figure 6.- Distribution of the sea surface temperature (SST, in °C, left panel) and sea surface temperature anomalies (SSTA, in °C, right panel) during February-March 2019, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 1802-03, 12 February – 27 March 2019 (during the declining phase of the weak 2018-2019 El Niño)

Also, during warmer March-April 2017 period, the spatial distribution of the sea surface salinity (SSS) and the sea surface salinity anomalies (SSSA) in Figure 7, in conjunction with the SST and SSTA (Figure 4), indicate the unusual displacement of Tropical Surface Waters as far south as Chimbote (09°04'S) and the presence of Subtropical Surface Waters to the south of Chimbote, very close to the coast at 10°00'S and 15°30'S. While the Cold Coastal Waters were restricted to a narrow coastal area to the south of 16°00'S, at no more than 30 nm from the coast.

During the cooler February-April 2018 period, the distribution of SSS and SSSA (Figure 8) and SST and SSTA (Figure 5) indicate that the Tropical Surface Waters had moved back north, between Paita and Punta la Negra (5°05' - 6°00'S), while the Cold Coastal Waters were found in more oceanic areas further offshore off Punta la Negra (5°05'S) and along coastal areas off Huacho (11°07'S) and further south. It is noted that the mixed layer of warm Subtropical Surface Waters and Cold Coastal Waters that had almost disappeared and/or moved very close to the coast during the warmer than normal conditions in March-April 2017 appeared within the 40 nm from the coast between Mórrope (6°35'S) and Salaverry (8°13'S) in February-April 2018.

Figure 7.- Distribution of the sea surface salinity (SSS, in PSU, left panel) and the anomaly of the sea surface salinity (SSSA, in PSU, right panel) during March-April 2017, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 1703-04, 3 March - 13 April 2017

Figure 8.- Distribution of the sea surface salinity (SSS, in PSU, left panel) and the anomaly of the sea surface salinity (SSSA, in PSU, right panel) during February-April 2017, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 1802-04, 22 February – 6 April 2018
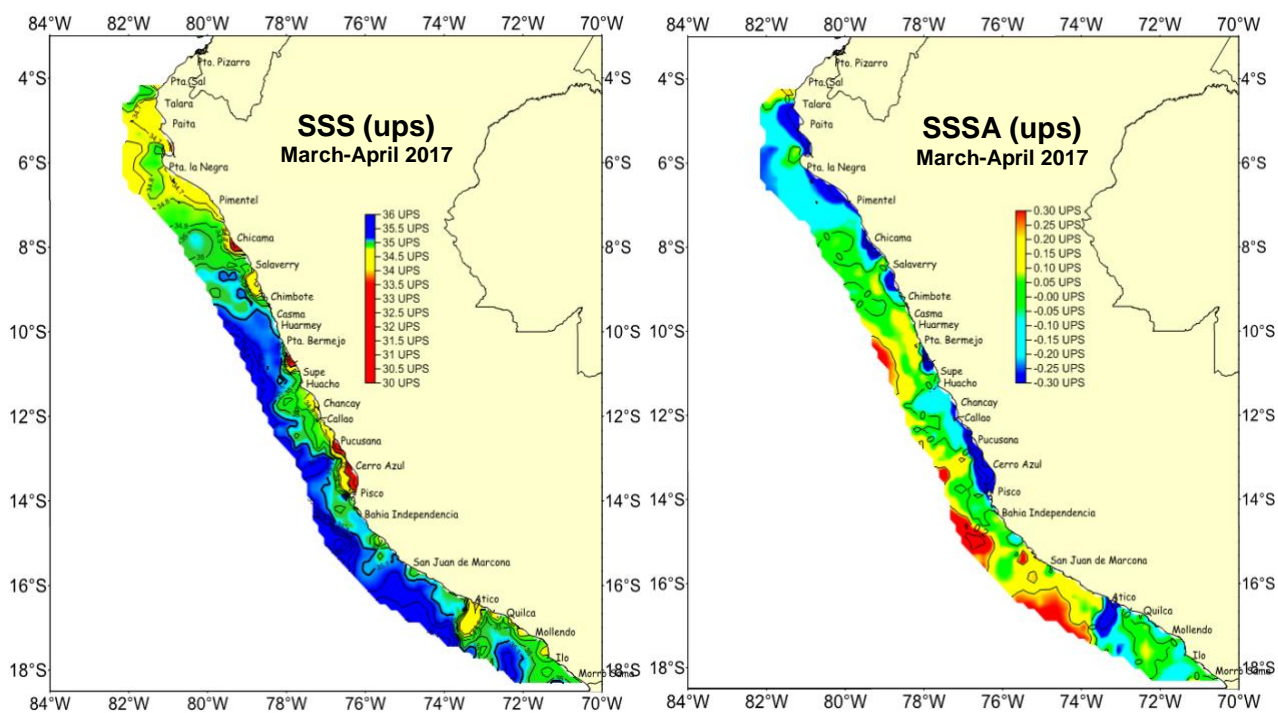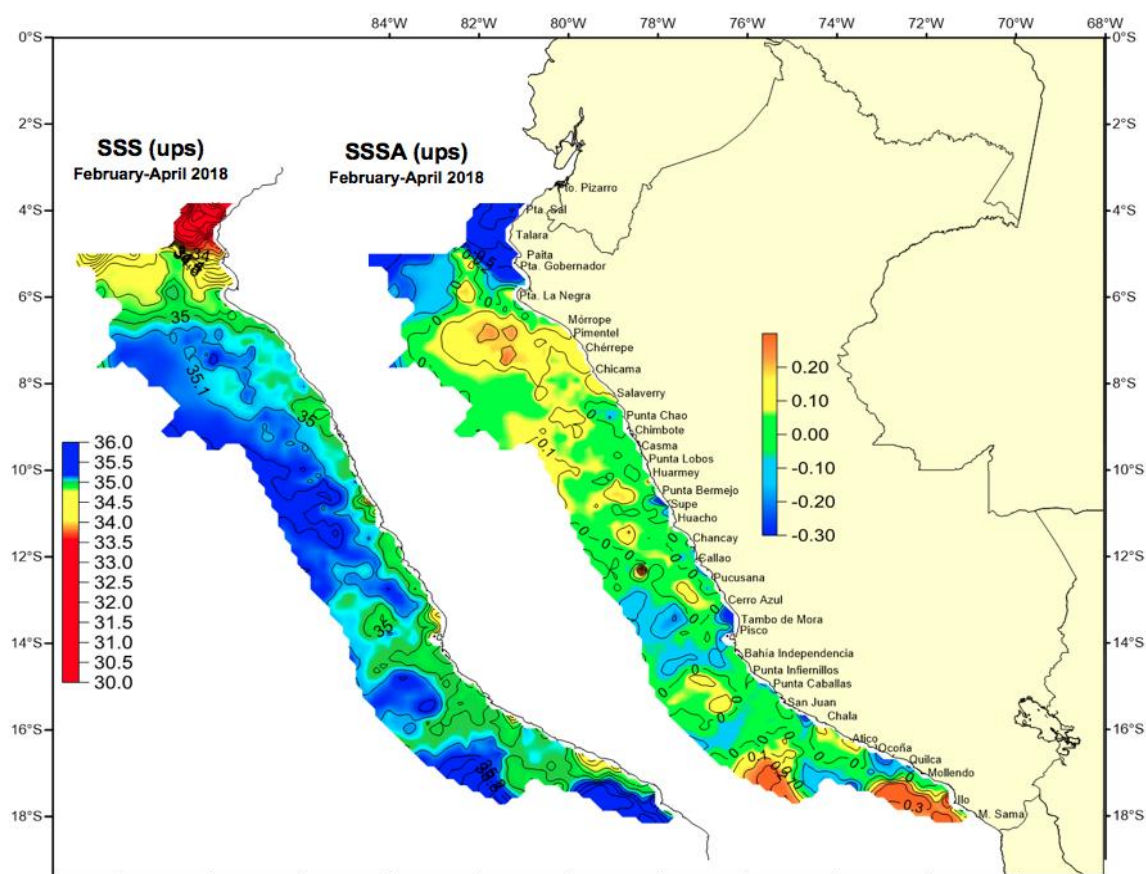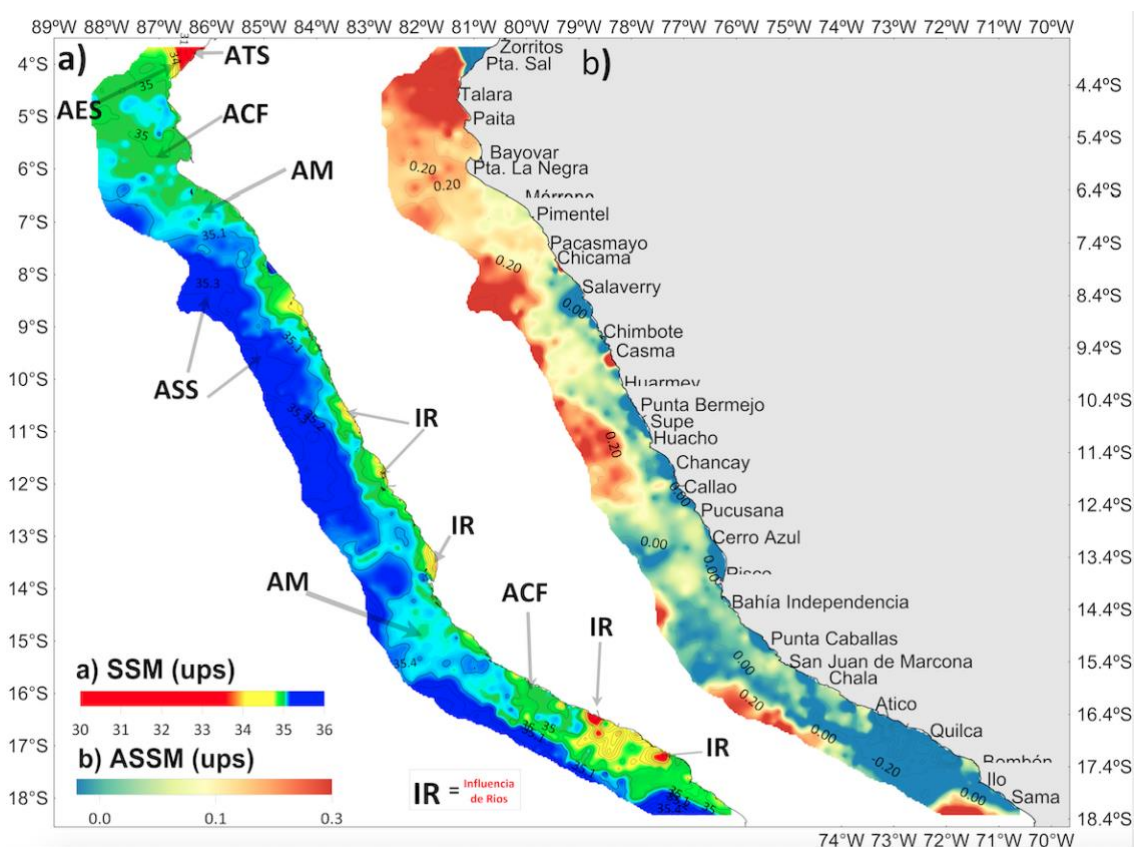
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Figure 9.- Distribution of the sea surface salinity (SSS, in PSU, left panel) and the anomaly of the sea surface salinity (SSSA, in PSU, right panel) during February-March 2019, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 1902-03, 12 February – 27 March 2019

During the warmer than normal February-March 2019 period, the distribution of SSS and SSSA (Figure 9) and SST and SSTA (Figure 6) indicate the presence of the Tropical Surface Waters to the north of Talara (4°34'S) and the Subtropical Surface Waters at 20 nm from the coast between Pimentel (6°50'S) and Pisco (13°43'S) and beyond the 50 nm from the coast further south, between San Juan de Marcona (15°22'S) and Morro Sama (18°00'S).

3. CHARACTERIZATION OF THE STOCK

A brief update on the main biological and behavioral observations reported in last year's report (IMARPE-PRODUCE 2018) is provided below.

3.1. Spatial distribution

The alternating warmer and cooler than normal environmental conditions that have prevailed along the Peruvian coast due to the weak 2014 El Niño, the strong 2015-2016 El Niño, the moderate-coastal 2017 El Niño, the weak-to-moderate 2017-2018 La Niña and the weak 2018-2019 El Niño, have caused the more or less persistent displacement and dispersion of the Jack mackerel concentrations until mid-2018, and have favored the presence of denser concentrations in late 2018 and, in particular, during the first part of 2019.

During 2014 and particularly during 2015, 2016 and up until the first part of 2017, Jack mackerel concentrations of commercial interest were only found in coastal areas, within the 10-20 nm distance from the coast, within reach of the artisanal and small-scale fleets but outside the reach and usual fishing grounds of the industrial purse

seine fleet. As reported last year, this change in the spatial distribution of Jack mackerel in 2014 and particularly during 2015, 2016 and early 2017 was closely related to the closing in towards the coast of the Subtropical Surface Waters and the near disappearance of the mixed layer with Cold Coastal Waters caused by the strong 2015-16 El Niño and the moderate 2017 coastal El Niño.

The situation didn't change much as far as the distribution and dispersal of the Jack mackerel concentrations of commercial interest that continued to be available only to artisanal and small-scale fleets closer to the coast during the first part of 2018, with the predominance of Cold Coastal Waters associated with the weak-to-moderate 2017-2018 La Niña. This situation was temporarily reversed 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, favoring the presence of denser Jack mackerel concentrations at 20 to 80 nm from the coast, particularly between Chimbote (9°04'S) and Pisco (13°43'S), within the easier reach of the industrial purse seine fleet.

3.2.   Age and growth

The few age readings and length frequency distributions analyzed by the conventional methods between 2014-2018 and first months of 2019 fall within the range of observations and growth estimates described by Dioses (1995, 2013), Goicochea *et al.* (2013) and Diaz (2013) and the parameters of the von Bertalanffy growth function in use by IMARPE, where: L_∞ = 80.77 cm total length, k = 0.1553 y^{-1} and t_o = -0.3562.

3.3.   Reproductive aspects

The observed monthly variability of the gonadosomatic index (GSI) of Jack mackerel in Peruvian waters (Figure 10) indicate that after the above normal 2012-2013 reproductive cycle, the intensity of the reproduction process has been consistently low and/or out of phase with respect to the 2002-2012 mean values taken as standard. Moreover, throughout most of 2018 and 2019 the observed monthly GSI have been amongst the lowest on record, making the 2018-2019 reproductive cycle a flatten to almost nonexistent one. However, the low GSI values during the 2018-2019
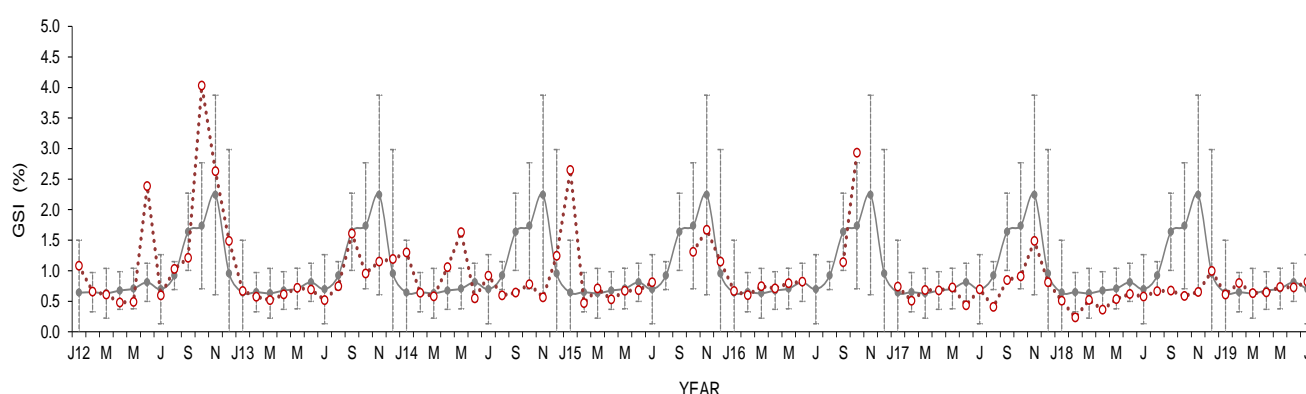
Figure 10.- Monthly variability of the Gonadosomatic Index (GSI) of Jack mackerel larger than 26 cm TL caught in Peruvian jurisdictional waters. The dark line and markers represent the long-term monthly mean for the years 2002-2012, taken as the standard and the grey vertical lines represent their respective standard deviations. The red circles and broken lines are the actual observed monthly values from January 2011 to July 2019. Updated from Perea *et al.* (2013)

reproductive cycle seem related with the predominance of juveniles (40 to 64%) in the catches, and the biological samples, taken in September-December 2018.

3.4. Trophic relationships

The updated information on food content based on the work by Alegre *et al.* (2013, 2015) 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 taxa groups), although during most of the last 46 years there has been a clear predominance of euphausids (Figure 11).
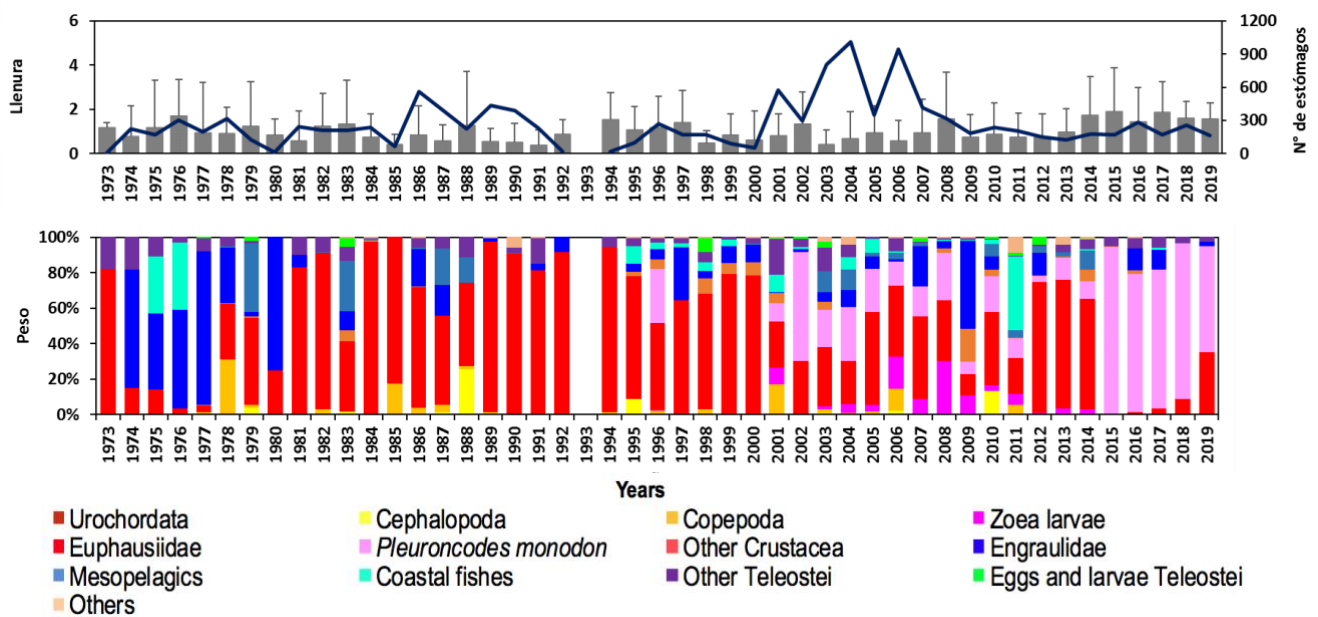

Figure 11.- Index of fullness (in %, vertical bars, top panel), sample size (solid lines, top panel) and proportion of preys (vertical bars, lower panel) in stomach content of Jack mackerel *Trachurus murphyi* off Peru from 1973 to 2019 (January-June 2019 only). Updated from Alegre *et al.* (2013, 2015)

The dominance of euphausids 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, euphausids continued to be an important component of the Jack mackerel diet, although there has been 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, which has been particularly abundant, probably benefitting from the influence of the strong 2015-2016 El Niño and the moderate 2017 coastal 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 (SSW) at 10°S and 15°30'S and of the Cold Coastal Waters (CCW) from 16°S south, and the very coastal distribution of most of the catches and samples taken in 2015-2018.

4. DESCRIPTION OF THE FISHERY

There are two major groups of vessels authorized to fish for Jack mackerel in Peruvian national waters: the industrial purse seine fleet, with 104 industrial purse seine vessels with holding capacity larger than 36.2 m³; and, the small-scale and artisanal fleets, with vessels having a maximum hold capacity of 32.6 m³. The small-scale fleet includes around 100 small, lightly mechanized, purse seine vessels with an average hold capacity of 12 m³; and, the artisanal fleet, which may include as much 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 m³ are the ones most frequently fishing for Jack mackerel, mostly with small purse seines or hock and line.

The industrial purse seine fleet participates in two types of pelagic fisheries, during distinct fishing seasons. 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. Which, by law, can only be used 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 one or the other (*i.e.:* anchoveta or 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 going 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

As shown in Figure 12, 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 since the fishery started. Catches during the first part of 2018 were also pretty low. And, as already noted, these low catches appear to be closely 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.
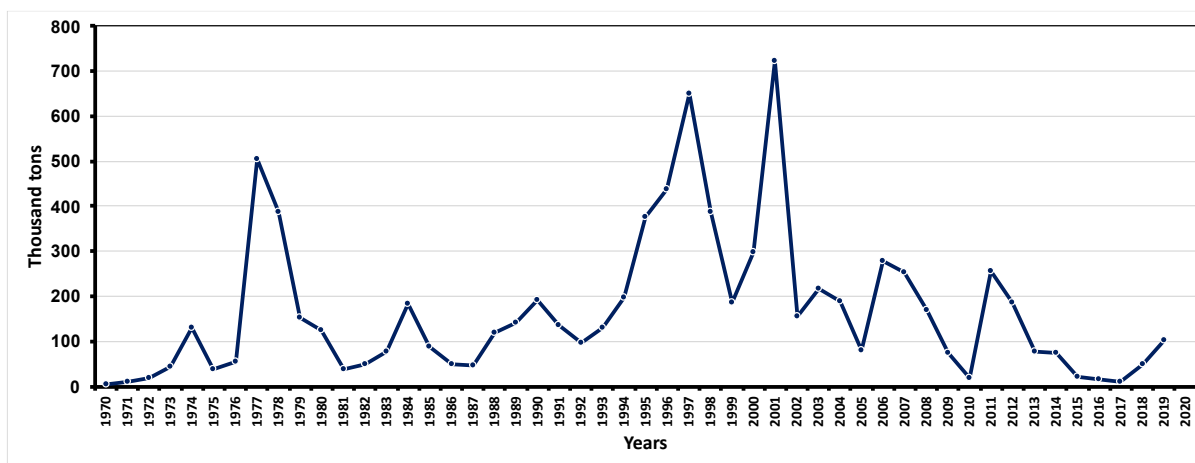

Figure 12.- Annual landings of Jack mackerel (*T. murphyi)* in Peru, years 1970-2019 (updated to July 2019)

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 reported during this period were taken by much smaller vessels of the artisanal and the small-scale purse seine fleets.

Towards the end of 2018 the total annual catch of Jack mackerel significantly increased with respect to the annual totals for 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. These high catches were made almost entirely by the industrial purse seine fleet.
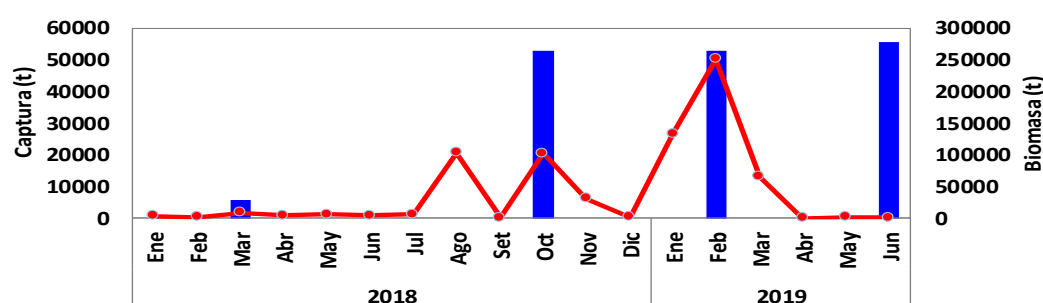

Figure 13.- Monthly landings of Jack mackerel (*Trachurus murphyi*) (red lines) and estimated biomass in selected months (blue bars), total Peru, between January 2018 and June 2019

The increasing trend in Jack mackerel catches continued during the first part of 2019. On this, it is worth noting that just within the first three months of 2019, the total catches almost doubled those of the whole year in 2018 and six-fold those taken by year between 2015 and 2017. All this even if 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 close during January and February 2019 and the first part of March 2019.

The above recent increase in monthly Jack mackerel catches during 2018 and 2019 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 CPUE
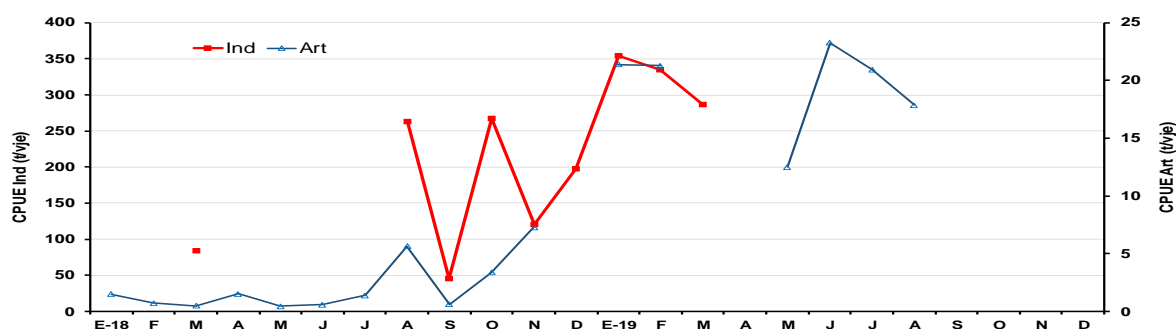

Figure 14.- Monthly catch per unit of effort (CPUE, in tons per trip) of Jack mackerel (*Trachurus murphyi*) by the industrial purse seine fleet (red lines) and by the artisanal purse seine fleet (blue lines) fishing in Peruvian waters between January 2018 and August 2019

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of both fleets started to increase by August 2018 and had increased and remained at high levels throughout the second part of 2018 and the beginning of 2019.

There is CPUE data from the industrial purse seine fleet only until March 2019 since as of the 24th March 2019 the fishing season for Jack mackerel by this fleet was closed until further notice. The artisanal fleet continues to fish for Jack mackerel as well as for other fishery resources this fleet is authorized to fish for, with the only major constrain that their catches be handled and used for direct human consumption. it is also worth noting that during May-August 2019, the CPUE from the artisanal fleet has remained at the same high levels observed during January-March 2019.

4.2. Fishing areas

As during 2015, 2016 and 2017, during the first part of 2018 the fishing grounds for Jack mackerel by the artisanal and small-scale purse seine fleets have had a very coastal geographical distribution. While, even if their catches were low, the fishing
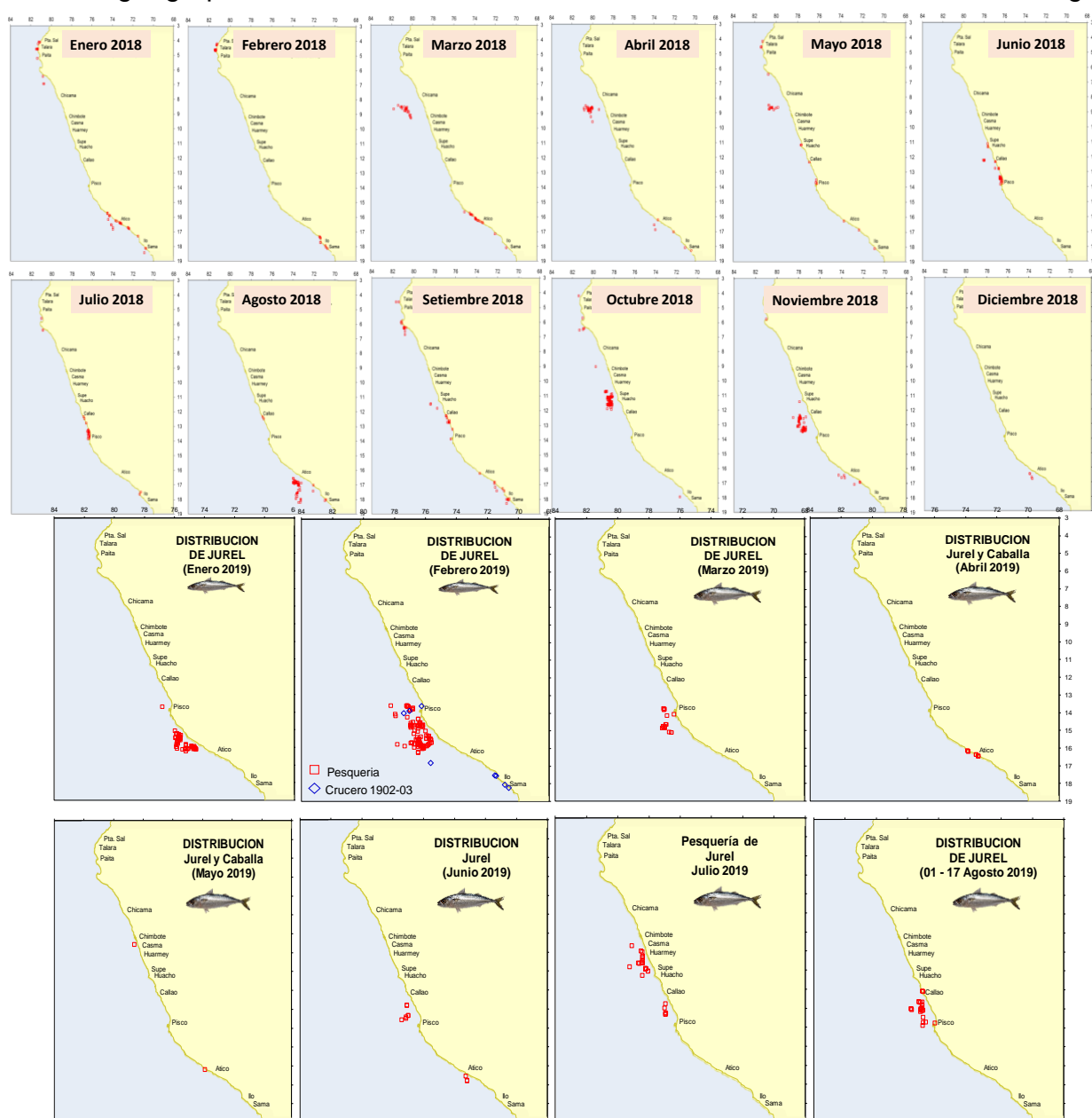

Figure 15.- Distribution of the Jack mackerel (*Trachurus murphyi*) fishing areas in Peru, by month, from January 2018 to August 2019

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grounds of the industrial purse seine fleet were farther offshore, located off Chicama-Chimbote (between 7°55' and 9°04'S) in March-May 2018 (Figure 15, top panel). The monthly catches by the industrial purse seine fleet increased noticeably in August, October and November 2018 and their fishing grounds were also farther offshore, mostly south of Atico (16°14'S) in August, off Supe-Huacho (between 10°45' and 11°07'S) in October, and off Callao-Pisco (between 12°03' and 13°43'S) in November 2018.

Monthly catches by the industrial purse seine fleet continue to increase in January and February 2019 and continued to be high in March 2019, with their main fishing grounds remaining farther offshore, south of Pisco (13°43'S). While the fishing grounds of the artisanal and small-scale purse seine fleets, that usually fishes for Jack mackerel year-round, were closer to the coast but not as coastal as in previous years, suggesting a wider distribution of the Jack mackerel in 2019.

4.3. Size structure

The monthly size frequency distributions of Jack mackerel observed in the Peruvian fisheries between January and December 2018 (Figure 16) shows that the fishery targets on a wide range of sizes of Jack mackerel, with unimodal or multimodal groups, and sizes ranging from 14 cm to 52 cm in total length (TL). Figure 16 also indicates a
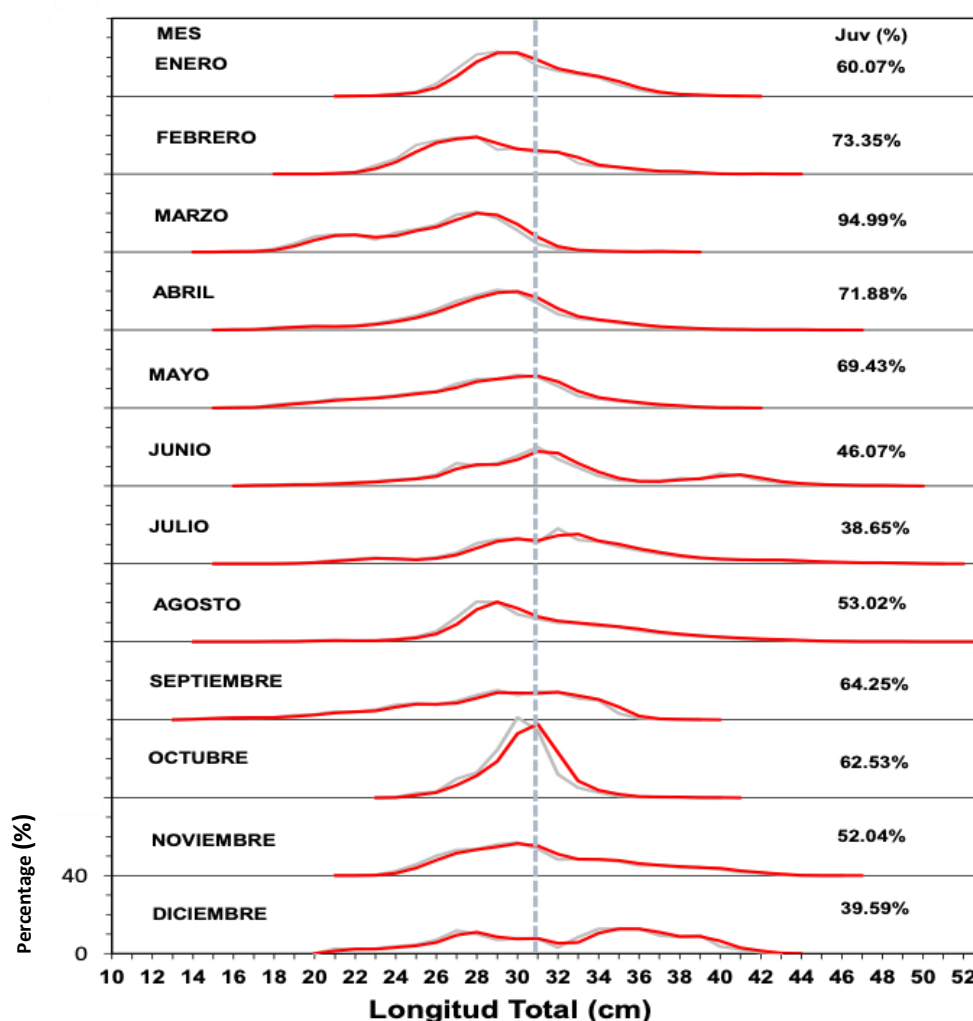

Figure 16.- Size frequency distribution of Jack mackerel (*Trachurus murphyi*) caught in Peruvian waters by all fleets by month between January and December 2018

consistent presence of juveniles, with fish smaller than 31.0 cm TL, that represented up to 95% of the total catch in numbers in March 2018, and as low as 39% in July and December 2018. The smaller-size modal group was observed in March 2018 (modal size around 21 cm TL) and the largest-size modal groups were observed in June and July 2018 (modal size around 41-42 cm TL).

Jack mackerel caught between January and August 2019 were much larger than those caught in 2018, with some multimodal but mostly unimodal groups, and sizes ranging from 14 cm to 52 cm TL Figure 17. Most of the Jack mackerel caught during this period were adults, with a low proportion of juveniles. The highest catches were made during the first three months, when the percentage of juveniles in numbers was as low as 2.4% in February and March 2019, and the main modal sizes were at 35-36 cm TL.

A new cohort with modal size at 29 cm TL entered the fishery in April 2019 and raised the proportion of juveniles to 68%. The proportion of juveniles decreased noticeably in the following months as the modal size of the main modal groups progressed towards 34 cm TL by July and August 2019.
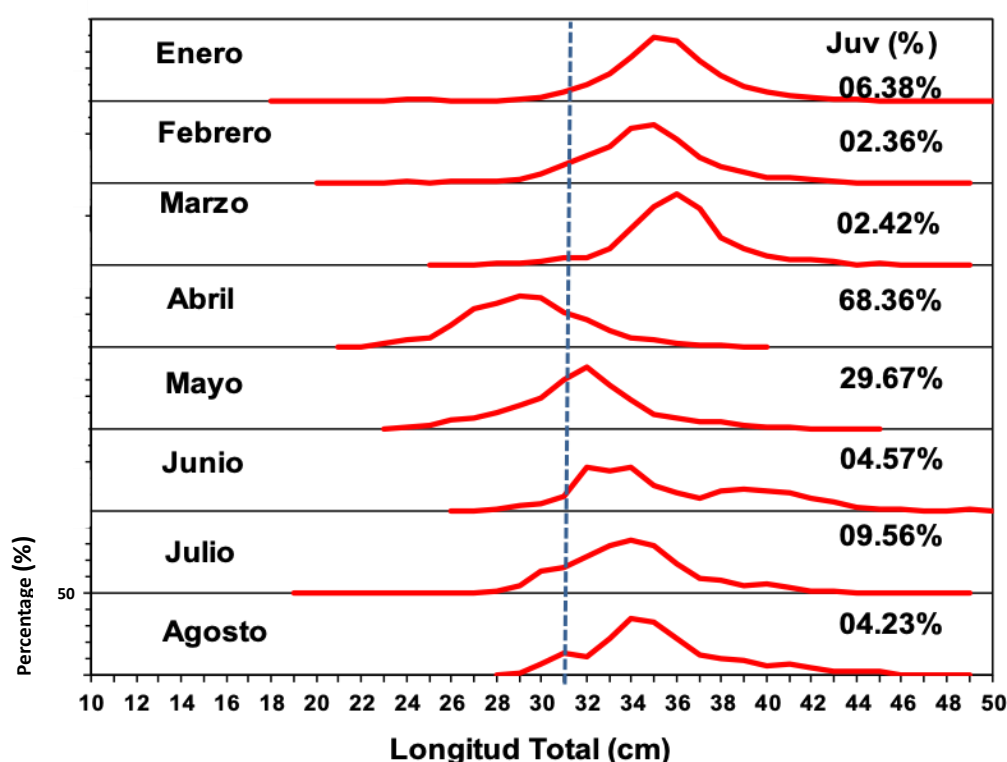
Figure 17.- Size frequency distribution of jack mackerel (*Trachurus murphyi*) caught in Peruvian waters by all fleets by month between January and 17 August 2019

5. STOCK ASSESSMENT

This section provides a brief summary of the 2018 assessment of the Peruvian stock of Jack mackerel (far-north stock) followed by a 2019 review and update with the Joint Jack Mackerel (JJM) model made by IMARPE using the most recent data and information.

5.1.   2018 assessment and 2019 TAC

In early January 2019 IMARPE updated the available 2018 Jack mackerel assessment in order to advise the Vice-Ministry of Fisheries on the most current situation of the

stock and the estimated Total Allowable Catch (TAC) for 2019. This assessment was based on the latest version of the JJM model developed during the 6th Meeting of the Scientific Committee held in Puerto Varas, Chile, in September 2018 (SPRFMO 2018), with all data and information updated to December 2018.

The stock size estimated in January 1st 2019 was projected to the end of the year under several exploitation scenarios, each one related to a TAC and to a relative reduction 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 2020 be lower than that estimated for January 1st 2019.

A range of F values was taken in consideration for the estimation of the 2019 TAC, and an F value equal to twice the F of the last three years was considered as a conservative and precautionary enough F value for 2019, given the data and information available for 2018 and previous years. Which, as noted above, were characterized by the occurrence of a strong 2015-2016 El Niño, during 2015 and the first half of 2016, a moderate-coastal 2016-2017 El Niño and a weak-to-moderate 2017-2018 La Niña, which negatively affected the distribution and availability of Jack mackerel to the fishing fleet, resulting in exceptionally low annual catch and F values for those years, even if the biomass estimates were relatively high and fully capable of supporting higher catches than those observed.

This assessment resulted in a precautionary estimated TAC of 79 000 t for 2019, with an F_{2019} value of 0.032 and an estimated risk of 17.5% that the biomass projected to January 1st 2020 be lower than that estimated for January 1st 2019. This TAC estimate was communicated in IMARPE's early 2019 advice to the Vice-Ministry of Fishery, noting that it could be readjusted if higher abundance and increased availability of Jack mackerel was to be observed though IMARPE resources surveys and its regular monitoring of the Peruvian fish stocks and fisheries.

5.1.1. *Readjusted 2018 assessment and 2019 TAC*

As part of its regular monitoring of the Peruvian fish stocks and fisheries, IMARPE conducted a first pelagic stock assessment research survey from 12 February to 28 March 2019 (Cr. 1902-03), that through its more coastal design was mainly focused on the assessment of the anchoveta stock, but also assessed the more coastal presence, distribution, abundance, etc., of other pelagic fishery resources, including mid-size pelagics such as Jack mackerel, chub mackerel, amongst others.

The information from this survey, together with the analyses of all the available data and information from the ongoing Jack mackerel fishery during January, February and March 2019 indicated that, in comparison with what was observed in 2018 and previous years, there were much denser concentrations and increased abundance and availability of Jack mackerel in Peruvian waters. This, together with the presence of up to four cohorts, including adults and juveniles, observed though the length frequency data from the fishery and research surveys conducted throughout 2018 and 2019, indicated that there was a much healthier situation and were better prospects in comparison with what was concluded based on information and data up to December 2018 only. Which, in accordance with the presupposed conditions communicated to the Vice-Ministry of Fisheries with the initial IMARPE advice, justified an upward revision of the recommended TAC, by an additional 20 000 t, bringing the revised TAC to 99 000 t for the whole year.

Additional and more recent information from the industrial purse seine fishery, a more recent pelagic stock assessment research survey from 20 May to 21 June 2019 (Cr. 1905-06) and the ongoing artisanal and small-scale fishery confirmed the presence of several cohorts, with juveniles and adults, of Jack mackerel in Peruvian waters; as well as denser concentrations, higher abundance indexes and an estimated biomass of at least 270 000 t, assessed in only part of the total distribution area of Jack mackerel in Peruvian waters. On this, it is known that Jack mackerel can be distributed over the whole Peruvian national jurisdictional waters up to 200 nm from the coast, and the May-June survey Cr. 1905-06 only covered areas of 40 to 80 nm from the coast between Paita (5°05'S) and Callao (12°00'S), 2 to 60 nm from the coast between Callao (12°00'S) and San Nicolás (15°16'S), and 2 to 100 nm from the coast from San Nicolás (15°16'S) to Morro Sama (18°00'S).

5.2. 2019 assessment

The main purpose of this latest 2019 assessment was to incorporate the newly observed CPUE abundance values and update the JJM model estimates with the most recent data and information up to Jun 2019, using the same configurations of the JJM of 2018.

5.2.1. Updated information used in the 2019 assessment

Information about catch, catch at length, and catch at age was updated to June 2019. The *echo-abundance,* selectivity and biological data (sexual maturity, age and growth, weight at age and M) was maintained 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 estimates 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 2018 was updated, now for the period 2002-2019 (Figure 18).
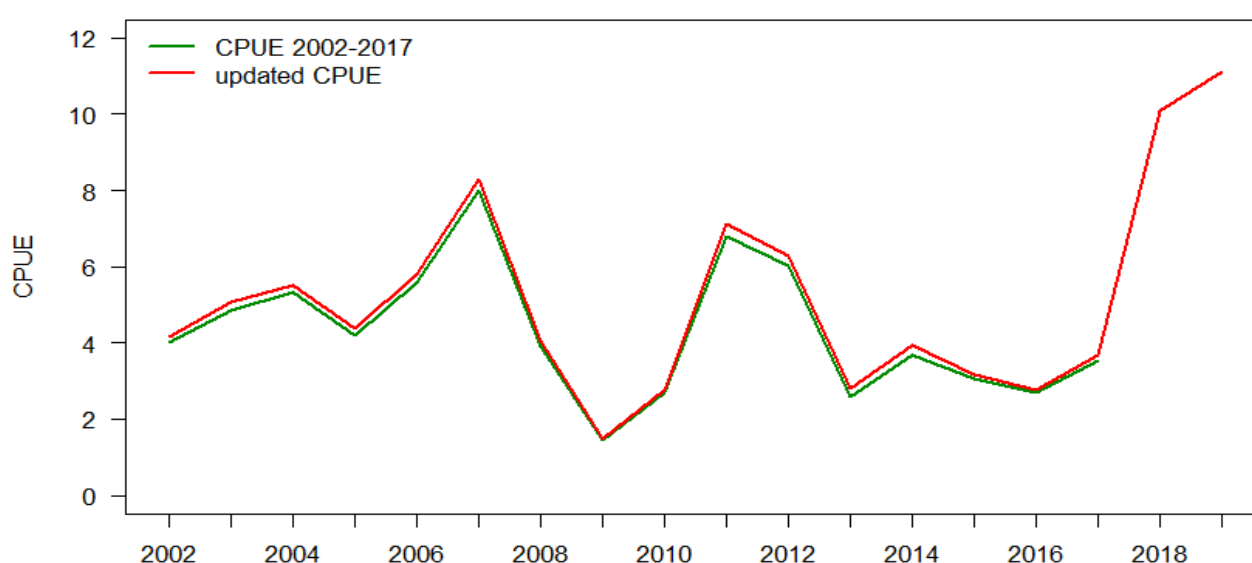

Figure 18.- Updated CPUE time series of Jack mackerel *Trachurus murphyi* caught in Peruvian jurisdictional waters by the industrial and the artisanal and small-scale fleets between 2002 and 2019

As in the previous year, the *echo-abundance* 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 records of echo-abundance of Jack mackerel only provide 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 conducted much closer to the coast (within 60 nm) 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. The pelagic stock assessment research survey conducted in May-June 2019 also covered an undetermined fraction of the total distribution of Jack mackerel in Peruvian waters and, therefore, was also not incorporate in the current 2019 JJM assessments.

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 2019 assessment of the Peruvian (far-north) Jack mackerel stock

Type	Data	Details
From the fishery	Catch	1970 – 2019
	Catch-at-length	1980 – 2019
	Catch-at-age	1980 – 2019
	CPUE	2002 – 2019
	Selectivity	Dome shaped
Fishery independent	Echo-abundance	1985 – 2014
	Selectivity	Logistic
Biological	Growth parameters	k=0.165 y^{-1}, L_∞=80.4cm
	Natural mortality	M=0.33
	Maturity at age	First mat=2 y
	Weight at age	From updated W-L parameters

5.2.2. 2019 Joint Jack Mackerel (JJM) model

The same configurations of the 2018 assessment were implemented in the 2019 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 2019 JJM assessment of the Peruvian (far-north) Jack mackerel stock

Model	Description
Data update	
0.0	- As 2018 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 2019
0.2	As in model 0.1 but with updated CPUE (2002-2019)
Model configuration	
1.0	As in model 0.2 (steepness = 0.8)
1.1	As in model 1.0 but steepness = 0.6

The addition of updated information, either length compositions, catches or CPUE (group 0 models), did not result in a substantial change in the overall trend of the total biomass, being almost the same. Two periods with marked contrast of productivity were still observed with group 0 models. The first one with very high biomass during the 1980s and 1990s, and the second one with lower biomass since 2000 (Figure 19a). Similarly, the mean value of fishing mortality estimated for years between 1970 and 2019 was very similar for the three configurations, as well as their distributions (Figure 19b).

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, and configuration 1.1 produced slightly higher values of biomass at the beginning of the series but similar values of biomass at the end of the series and, therefore, similar values of fishing mortality (Figure 19d).

The outputs of the final configuration show that the general trends and the biomass values in the latest period in this 2019 assessment are very similar to those in the 2018 assessment but with a slight increase in last two years.

The history and current situation of the unfished biomass, total biomass and annual fishing mortality of the Peruvian (far-north) stock are presented in the top three panels in Figure 20 and those of the stock and 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, 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 2018.

The period 1997-2000 was not considered 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.
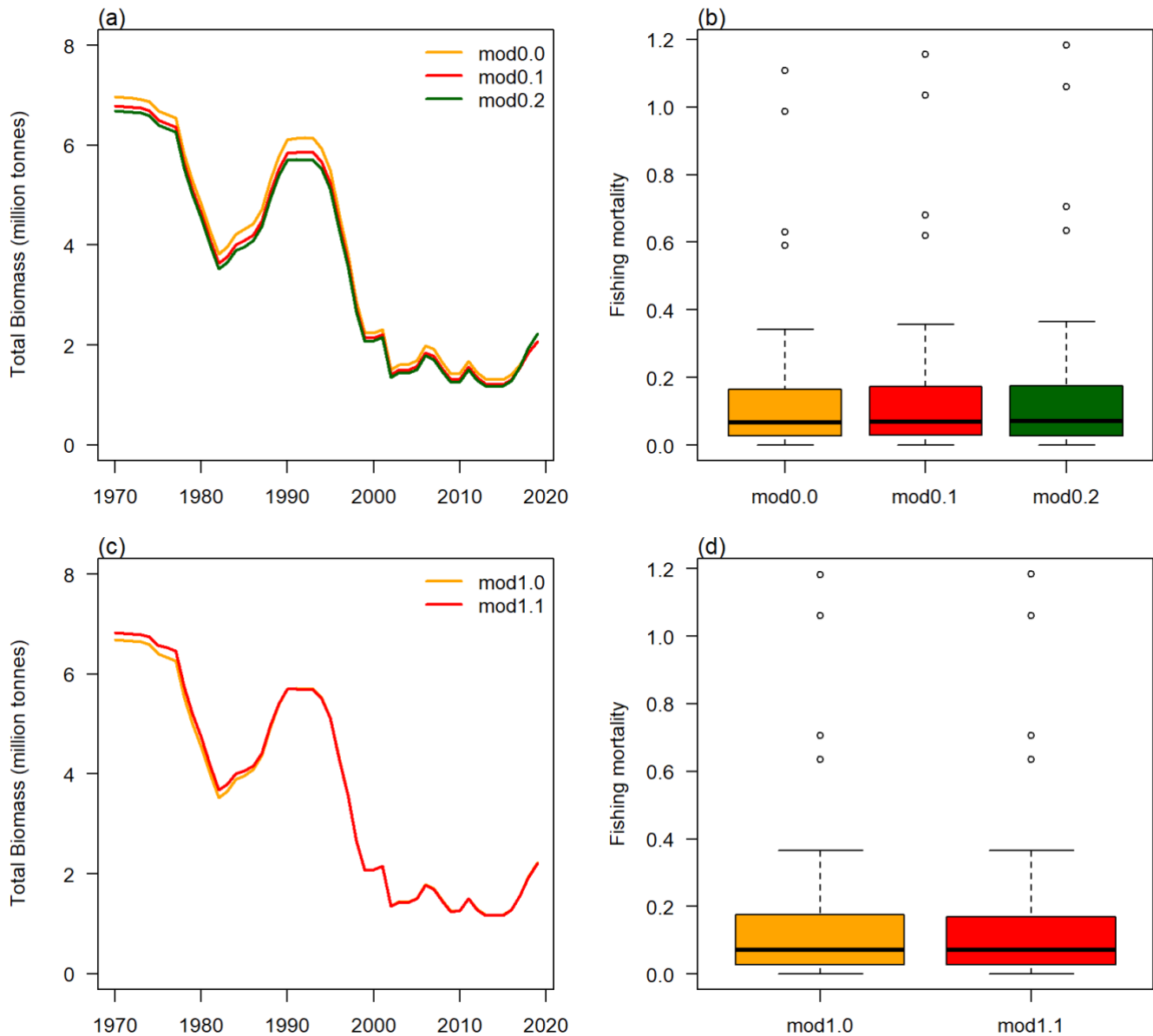
Figure 19.- Main outputs for the group 0 (top panel - testing the sensitivity to updated data) and group 1 (bottom panel - testing the sensitivity to assumptions on recruitment productivity) model configurations of the 2019 assessment with the Joint Jack Mackerel (JJM) model: (a) total biomass series (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

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

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