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Held virtually, 27 September to 2 October 2021

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Peru Annual Report - ANJ

Peru



INSTITUTO DEL MAR DEL PERU
IMARPE



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PRODUCE

**South Pacific Regional Fisheries Management Organisation
9th Meeting of the Scientific Committee
Held virtually, 27 September - 3 October 2021**

Peru National Report No. 2

**NATIONAL REPORT ON THE SITUATION OF THE
PERUVIAN STOCK OF JACKMACKEREL
(FAR-NORTH STOCK) AND THE PERUVIAN FISHERY
IN NATIONAL JURISDICTIONAL WATERS,
PERIOD JANUARY 2020 – JUNE 2021**

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.

2021

SUMMARY

The Peruvian marine environment is characterized by its high productivity and high variability and is particularly exposed to the effects of the opposed significantly warm (El Niño) and cold (La Niña) climatic patterns in the Pacific Ocean that alternate with relatively short periods of close to neutral or 'normal' conditions in Peruvian waters. Worth mentioning are the weak El Niño in mid 2014, the strong El Niño during 2015 and first half of 2016, the moderate-coastal El Niño from late 2016 to early in 2017, the weak-to-moderate La Niña from late 2017 to early 2018, the weak El Niño from late 2018 to early 2019 and the weak La Niña from the second half of 2020 to early 2021. All with transitional periods and closer to neutral conditions in between. These changing environmental conditions caused 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. And this has been followed by an expanded distribution in denser concentrations farther offshore, much higher abundance indexes, increased availability to the industrial purse seine fleet and higher catches of Jack mackerel during the second half 2018 and throughout 2019, 2020 and the first half of 2021. The poor 2018-2019 reproductive cycle has been followed by almost normal 2019-2020 and well above normal 2020-2021 reproductive cycles. At least four main size groups with a low incidence of juveniles were observed in the commercial catches throughout 2020 and the first part of 2021 while a fair presence of juveniles as small as 3 cm TL were observed during summer research surveys in 2020 and 2021. In late December 2020 IMARPE (Instituto del Mar del Peru) updated the available 2020 Jack mackerel assessment made for the Peruvian (far-north) stock with the JJM model during the 8th meeting of the Scientific Committee (SC08). This resulted in a range of options for setting the 2021 TAC that were included in its advice to the Government, recommending that a TAC for 2021 be established that considers a multiplier of F_{2020} not exceeding 2.0, which corresponded to a maximum estimated $F = 0.077$ and a maximum projected TAC = 132 000 t, accepting a risk of 45.1% that the estimated biomass by January 1st 2022 be lower than that estimated for January 1st 2021. Conservative catch limits aiming at a total catch limit of 101 000 t corresponding to the intermediate reference level recommended by IMARPE were set by the Government in January 2021. An updated assessment with the same JJM model has been made by IMARPE on the basis of the most recent information and data available up to June 2021. The recent observations and assessments confirm the increasing trend in the biomass estimates observed since 2016 as well as the overall healthy situation of the Peruvian Jack mackerel stock considering both, the natural low abundance regime through which the stocks appears to have been going through during the last two decades as well as the apparent intermediate stage or possible temporary shift being observed since 2019.

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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, 2019 and 2020).

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. Followed by a weak La Niña during the second half of 2020, with colder than normal conditions that have persisted until may 2021.

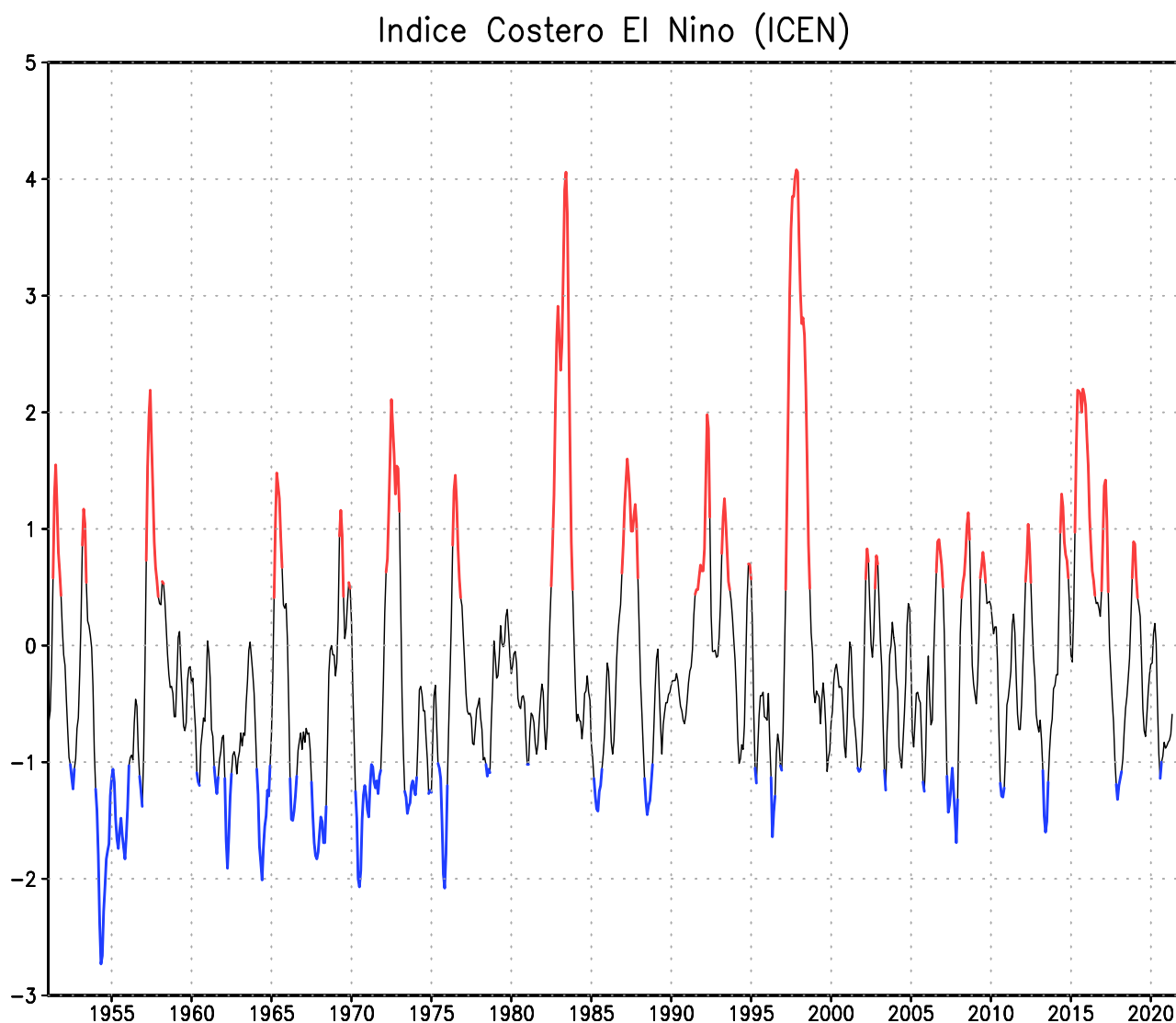
These environmental conditions contributed to the observed low abundance indexes and low catches of Jack mackerel (*Trachurus murphyi*) in Peruvian jurisdictional waters between 2014 and the first part of 2018. While the slightly warmer conditions during the last quarter of 2018 and first half of 2019 associated with a weak 2018-2019 El Niño, the slightly warm but close to neutral conditions during late 2019 and early 2020, the colder weak La Niña late in 2020 and still cold but closer to neutral conditions during the first half of 2021 contributed to a noticeable increase in both the abundance indexes and the monthly catches of Jack mackerel during the second half 2018 and most of 2019 and 2020, which remained high during the first half of 2021.

2. THE MARINE ENVIRONMENT

A strong El Niño developed off the Peruvian coast between April 2015 and April 2016. After a period of neutral conditions, there was a rapid and unexpected warming described as a moderate-coastal El Niño, lasting from late December 2016 to May 2017. Then there was a cooling period that generated a weak-to-moderate La Niña, which lasted from October 2017 to May 2018, followed by a brief period of slightly warmer than neutral conditions associated with a weak El Niño from late December 2018 to March 2019. Colder but close to neutral conditions followed from April 2019 to the end of the year, followed by warmer but still close to neutral conditions during the first months of 2020. By June 2020 the environmental conditions became colder than neutral, favoring the development of a weak La Niña towards the end of 2020, which lasted until may 2021. This cooling period peaked in August 2020 with an average sea surface temperature anomaly (SSSA) in the Niño 1+2 region of -1.14°C . This cooling continued during the first part of 2021, with average sea surface anomalies in the Niño 1+2 region of -0.86°C in January, -0.76°C in April and -0.59°C in May 2021.

The thermal conditions of the Peruvian marine environment have been changing noticeably in recent years, with thermal anomalies of varying extent and intensity. The weak regional El Niño of 2014 was followed by the strong 2015-2016 El Niño, the moderate coastal 2017 El Niño, the regional weak-to-moderate 2017-2018 La Niña, the weak 2018-2019 El Niño, a period of colder but close to neutral conditions towards the end of 2019 and of warmer but still close to neutral conditions in early 2020, followed by cool conditions and a weak La Niña during the second half of 2020, and the persistence of colder than neutral conditions during summer and the whole first part of 2021.

These changing environmental conditions are described by various indexes based on observations of the anomalies of the sea surface temperatures in oceanic and coastal areas off Peru, such as: the Coastal Index of El Niño (ICEN)) in the Niño 1+2 region (area between 0-10°S and 80-90°W), shown in Figure 1; the latitudinal distribution of the more local SSTAs 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 monthly mean sea surface temperature anomalies (SSTAs) observed between January 2015 and June 2021 shown in Figure 3, for the Niño 1+2 region (top panel) and for the more coastal areas along the Peruvian coast (bottom panel).



Data: ERSSTv5. Preparacion: IGP.
Ultimo dato: Mayo 2021.

Figure 1.- Coastal Index of El Niño (ICEN) in the El Niño 1+2 region, by month, from January 1950 to May 2021. 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)

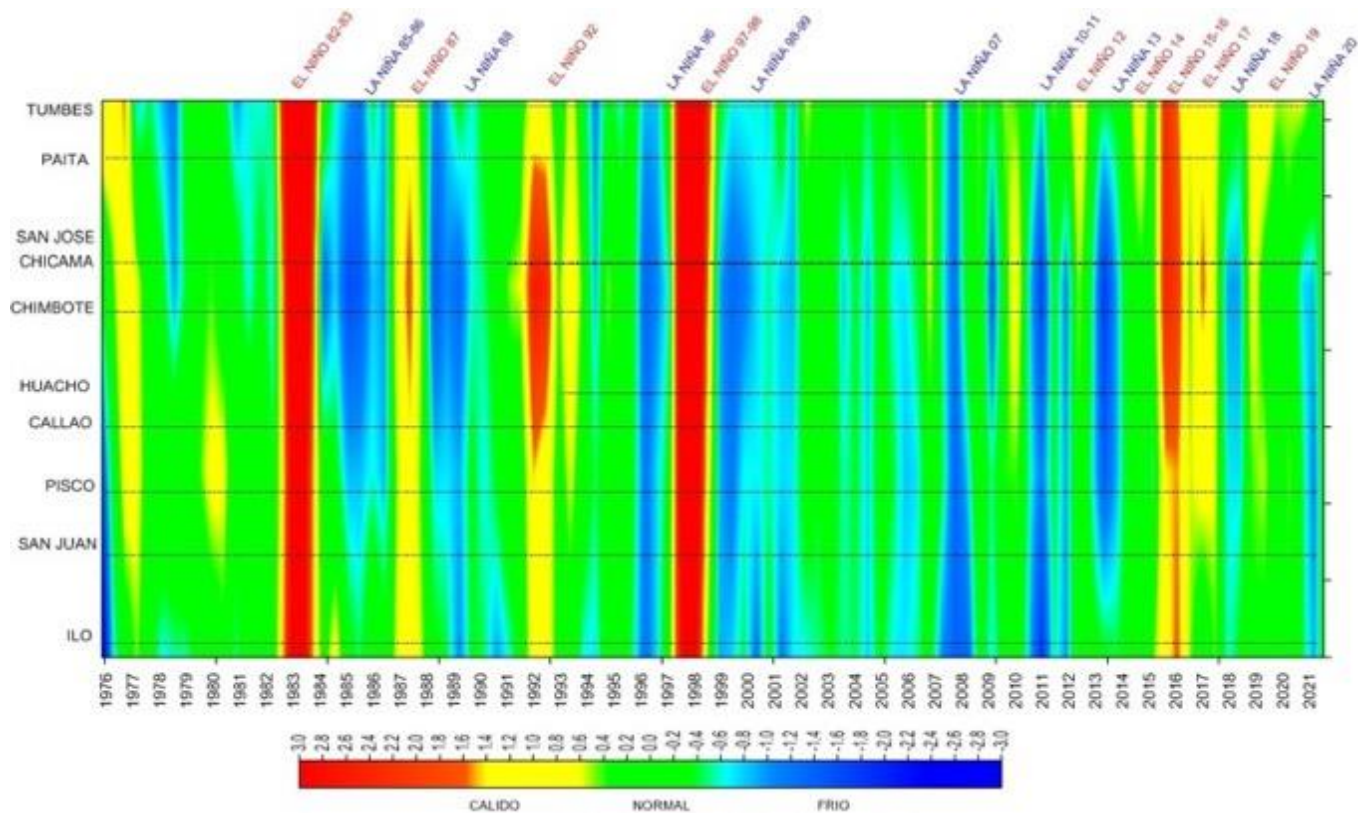


Figure 2.- Mean monthly sea surface temperature anomalies (SSTAs, in °C) from IMARPE's coastal laboratories and stations by latitude along the entire Peruvian coast, years 1976–2021 (until June 2021) (data source: IMARPE)

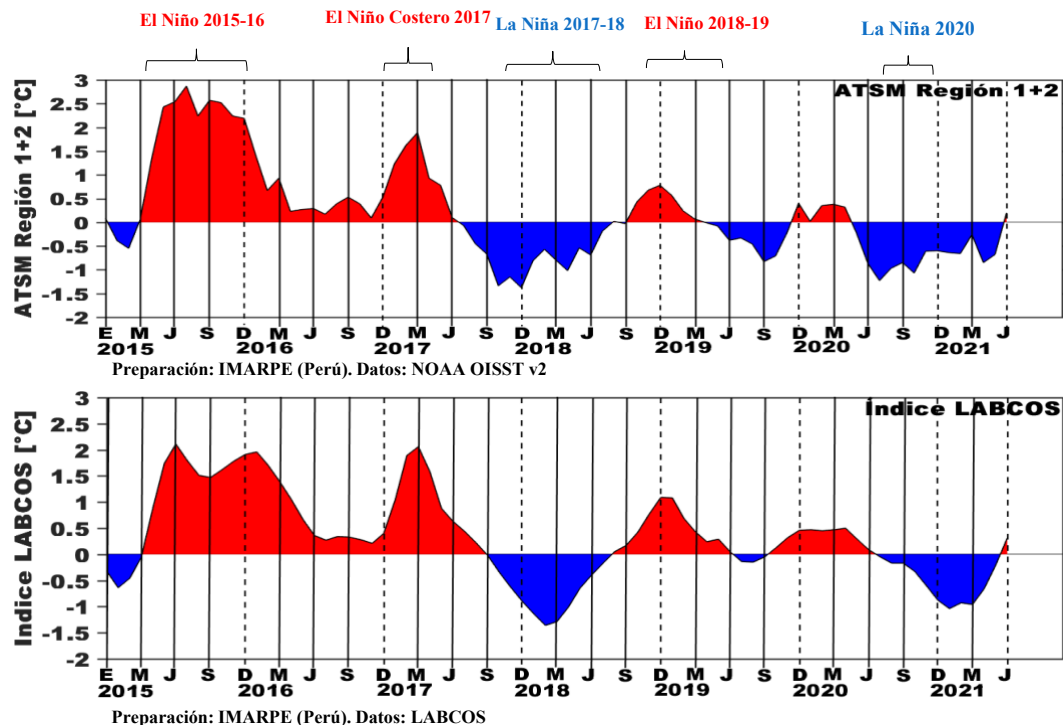


Figure 3.- Mean monthly sea surface temperature anomalies (SSTAs, in °C) in the coastal Niño 1+2 region (top panel) and along the Peruvian coastline as reflected by IMARPE's LABCOS index (bottom panel), from January 2015 to June 2021

As can be noted from the evolution of the SSTA indices in the figures above, the 2014 El Niño shows up as a weak one in the Niño 1+2 region (Figure 1) and appears even weaker along the Peruvian coast (Figure 2), where it had very mild effects limited to the northern part. While, as also noted in Figure 3, the strong 2015-16 El Niño was noticeable in the more oceanic El Niño 1+2 region as well 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 Peruvian coast as the previous two very strong El Niños of 1982-1983 and 1997-1998.

The moderate 2017 coastal El Niño followed, with 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 region 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 Niño 1+2 region and much later (between February-March 2018) 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, positive anomalies during the first quarter of 2020 and a clear cooling tendency particularly noticeable in the Niño 1+2 region by May 2020 and along the Peruvian coast by June 2020. Developing into a weak 2020 La Niña, with maximum negative SSTAs in August 2020 in the Niño 1+2 region (Figure 3, top panel) and in December 2020 along the Peruvian coast (Figure 3, bottom panel). Then the negative anomalies gradually diminished although the colder than neutral conditions remained until May 2021, to change to warmer than neutral in June 2021 with SSTA of +0.31°C in the Niño 1+2 region (ICEN) and of +0.2°C along the Peruvian coast.

The environmental conditions and extent of the changes along the Peruvian coast during the development of neutral conditions with predominance of positive SSTAs during the summer of 2020, the cooling due to a weak La Niña during the spring of 2020 and the development of neutral conditions with predominance of negative SSTAs during the summer of 2021 are also illustrated by the distribution of the sea surface temperature (SST) and its anomalies (SSTA) along the Peruvian coast during February-March (summer) 2020 in Figure 4, September-November (spring) 2020 in Figure 5, February-March (summer) 2021 in Figure 6, and by the sea surface salinity (SSS) and its anomalies (SSSA) in the same months, in Figures 7, 8 and 9.

During February-March 2020 (Figure 4) the SST off the Peruvian coast ranged from 16.6 to 27.1°C, with temperatures lower than 20.0°C in various areas within 10 nm of the coast between 7° and 17°S, particularly off Casma-Huarmey, Pisco-San Juan and Atico-Quilca, and temperatures above 25.0°C at more than 50 nm from most of the coast from the extreme north to Bahía Independencia and at more than 20 nm from the coast off Quilca. The SSTAs show a predominance of warm conditions throughout the area, with cold

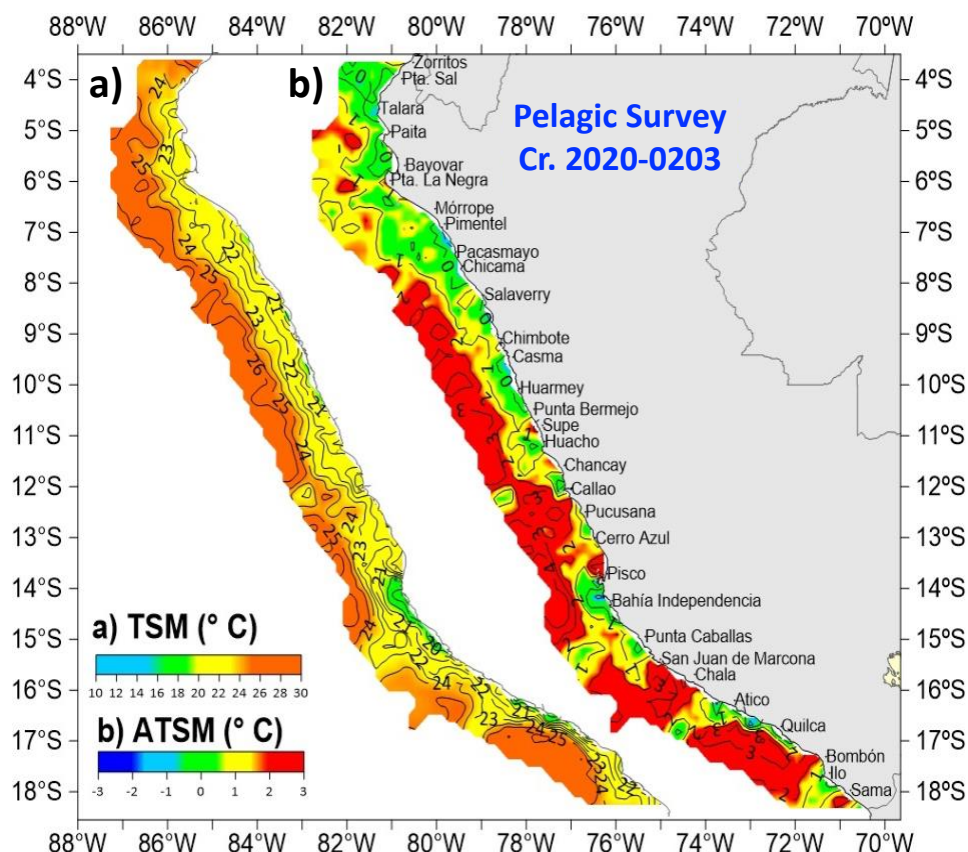


Figure 4.- Distribution of a) the sea surface temperature (SST, in °C, left panel) and b) the sea surface temperature anomalies (SSTA, in °C, right panel) during summer (February-March) 2020, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 2020-0203, 15 February - 27 March 2020

anomalies north of Chicama and warm anomalies that exceeded $+2.0^{\circ}\text{C}$ and up to $+3.0^{\circ}\text{C}$ in extended areas somewhat distant from the coast from Chicama to the south. These atypical conditions were due to the presence of strong southeast winds during the first fortnight of February that favored a stronger coastal upwelling and the consequent cooling of the sea surface mainly off the northern coast. However, during the third week of February, the arrival of a warm Kelvin wave with changes in the atmospheric circulation and the weakening of the southeast winds, favored the intrusion of warm waters from the north and west and the anomalous warming to along the Peruvian coast.

During September-November 2020 (Figure 5) the SST off the coast ranged between 12.7 and 23.4°C and the SSTA between -4.1 and $+2.6^{\circ}\text{C}$, with an average SSTA of -0.6°C for the whole studied area. Particularly warm conditions were recorded only in a relatively small pocket within 30 nm of the coast north of Talara with SSTA of up to $+2.6^{\circ}\text{C}$, associated with the advection of tropical waters from the north. But cold conditions prevailed in the rest of the coast, with negative anomalies greater than -2°C from Paita to the north, followed by anomalies between -1.0 and -2.0°C between Paita and Mórrope and lower negative anomalies in a larger area between Mórrope and San Juan de Marcona where one can note some nuclei with neutral conditions as well as a warm nucleus in front of Pisco. In general, those that dominated were cold conditions compatible with the development of the weak La Niña event of 2020.

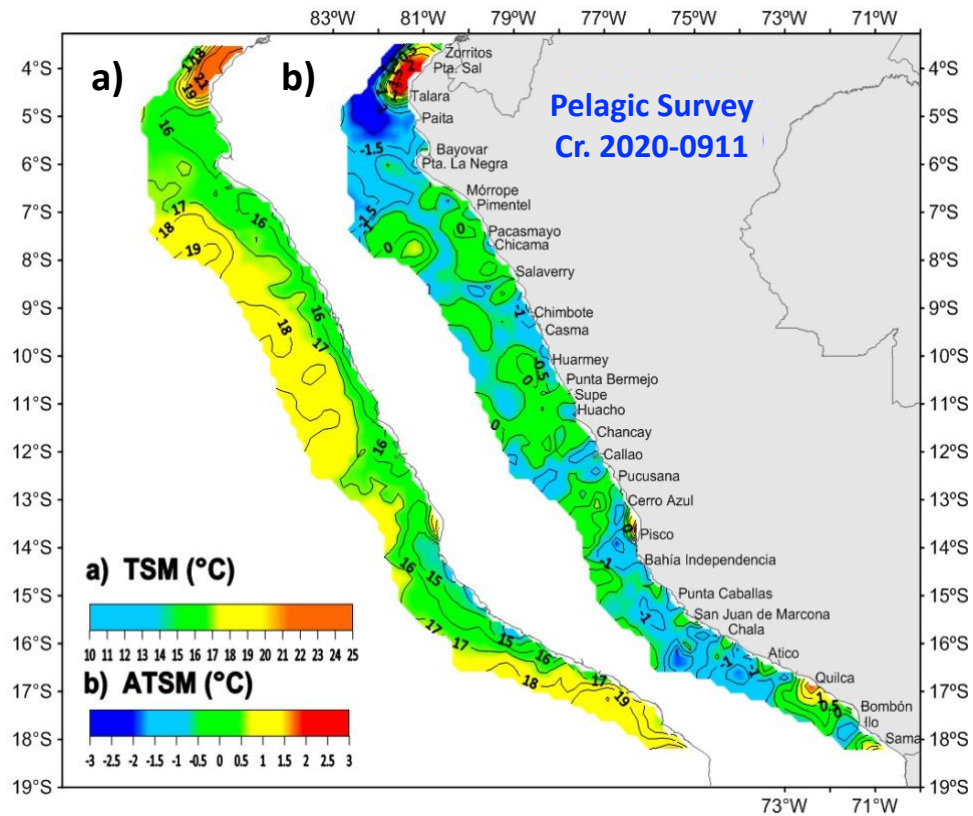


Figure 5.- Distribution of a) the sea surface temperature (SST, in °C, left panel) and b) the sea surface temperature anomalies (SSTA, in °C, right panel) during spring (September-November) 2020, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 2020-0203, 23 September – 13 November 2020

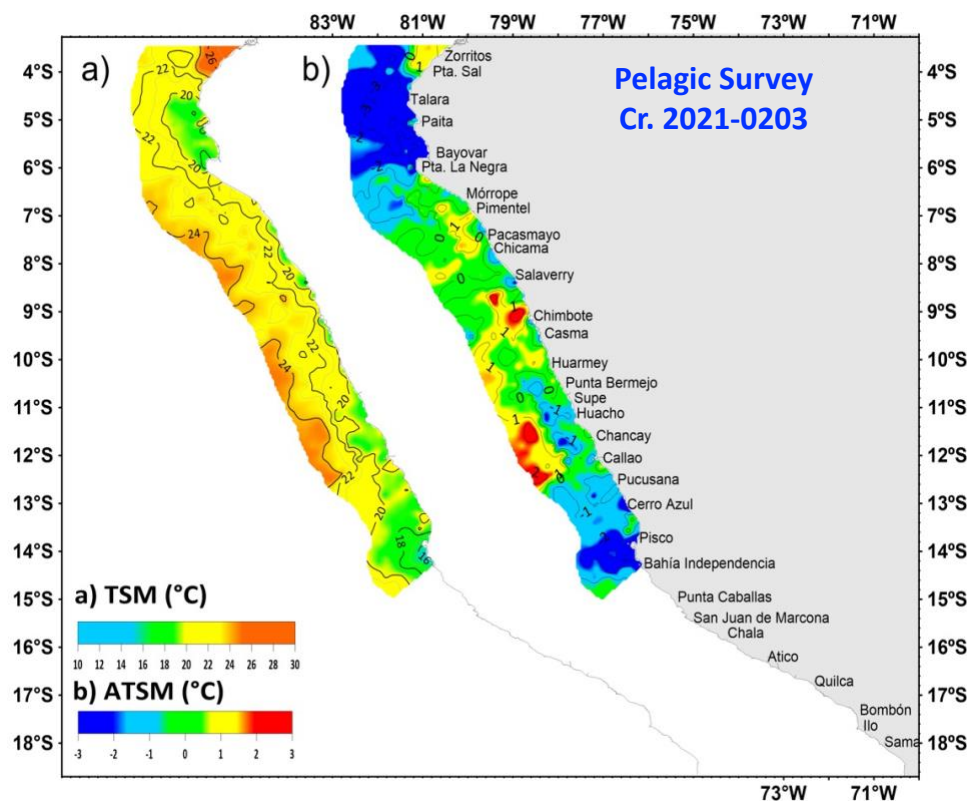


Figure 6. Distribution of a) the sea surface temperature (SST, in °C, left panel) and b) the sea surface temperature anomalies (SSTA, in °C, right panel) during summer (February-March) 2021, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 2102-03, 17 February - 31 March 2021

During February-March 2021 (Figure 6) the SST values were between 15.3 and 27.2°C and the SSTA were between -4.0 and +1.5°C. Warm conditions with SSTAs of up to +1.5°C due to the advection of tropical waters coming from the north are noted close to the coast north of Punta Sal, but outside this small coastal area cold thermal conditions prevailed. The maximum negative anomalies of up to -4.0°C were recorded to the north of Morrope, between Paita and Talara, while neutral conditions prevailed between Morrope and Huarmey, with some warm areas as well as other small cold areas closer to the coastline. Further south, between Huarmey and Callao there were warm conditions beyond 50 nm from the coast and cold conditions within the 50 nm, and cold conditions prevailed between Callao and Bahía Independencia with negative anomalies greater than -2.0°C south of Pisco.

The spatial distribution of the sea surface salinity (SSS) and the sea surface salinity anomalies (SSSA) during February-March 2020 (Figure 7) was atypical for the time of 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 cold coastal waters of the coastal upwelling between Bayovar and Chicama. Also, subtropical surface waters were usually found closer to the coast from Pimentel to the south, restricting the cold waters of coastal upwelling to small upwelling areas that persisted closer to the coastline, where there were also some spots with waters from the continental discharge (rivers). In general, the saline concentrations were higher during February-March 2020 than during the same period the previous year (February-March 2019).

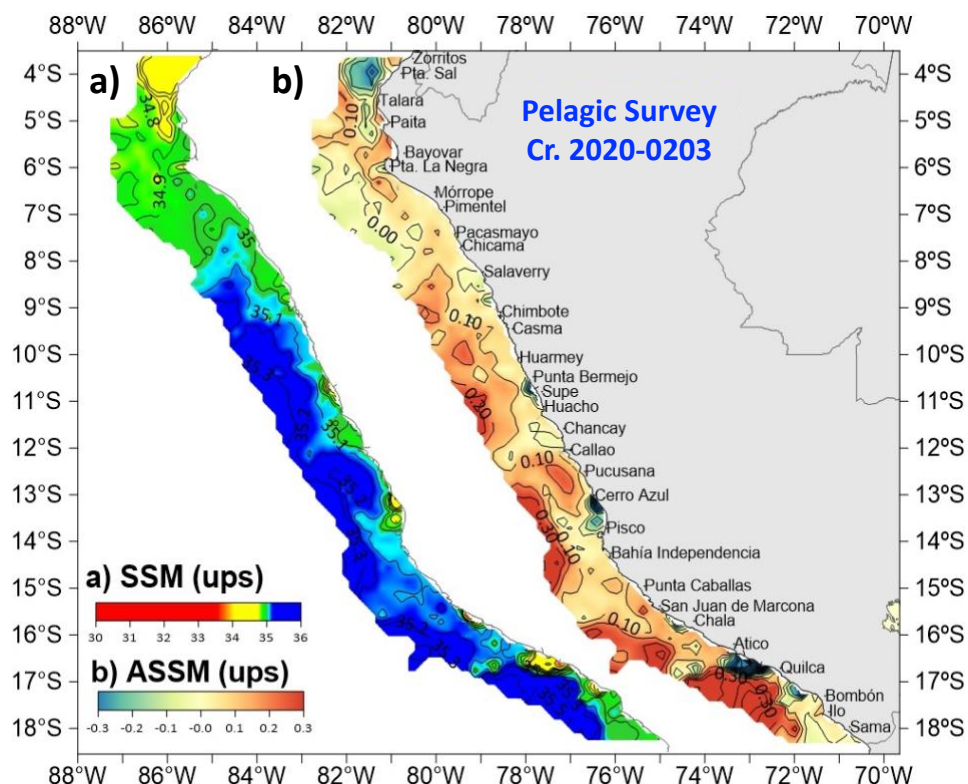


Figure 7.- Distribution of a) the sea surface salinity (SSS, in ups, left panel) and b) the anomaly of the sea surface salinity (SSSA, in ups, right panel) during summer (February-March) 2020, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 2020-0203, 15 February - 27 March 2020

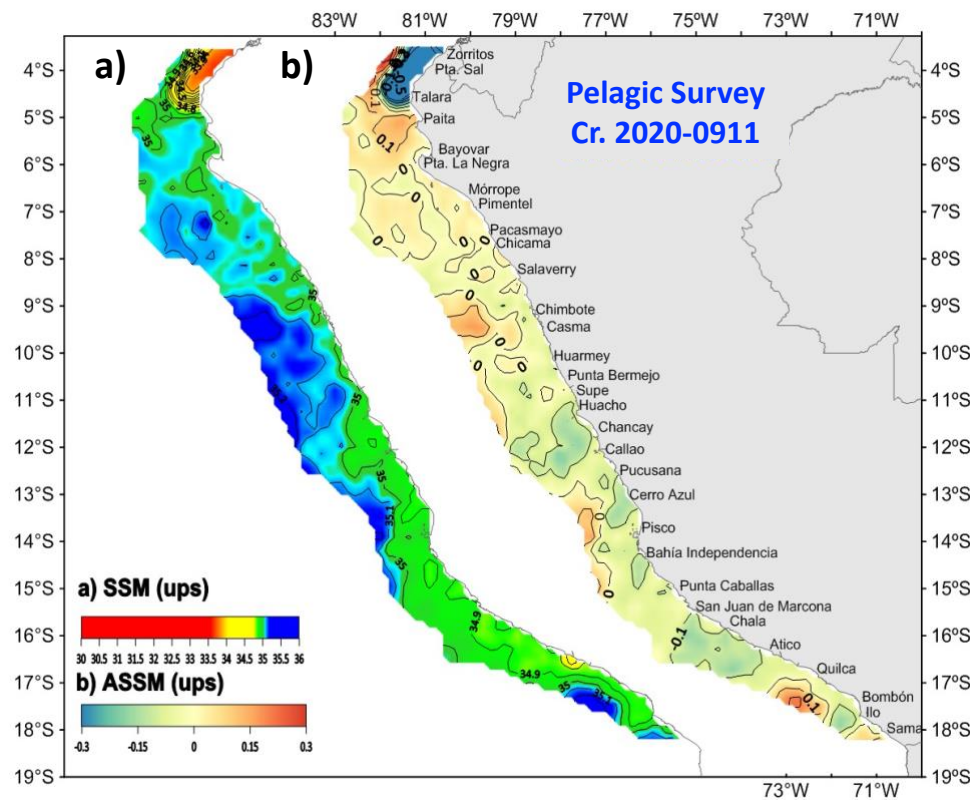


Figure 8.- Distribution of a) the sea surface salinity (SSS, in ups, left panel) and b) the anomaly of the sea surface salinity (SSSA, in ups, right panel) during spring (September-November) 2020, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 2020-0911, 23 September - 13 November 2020

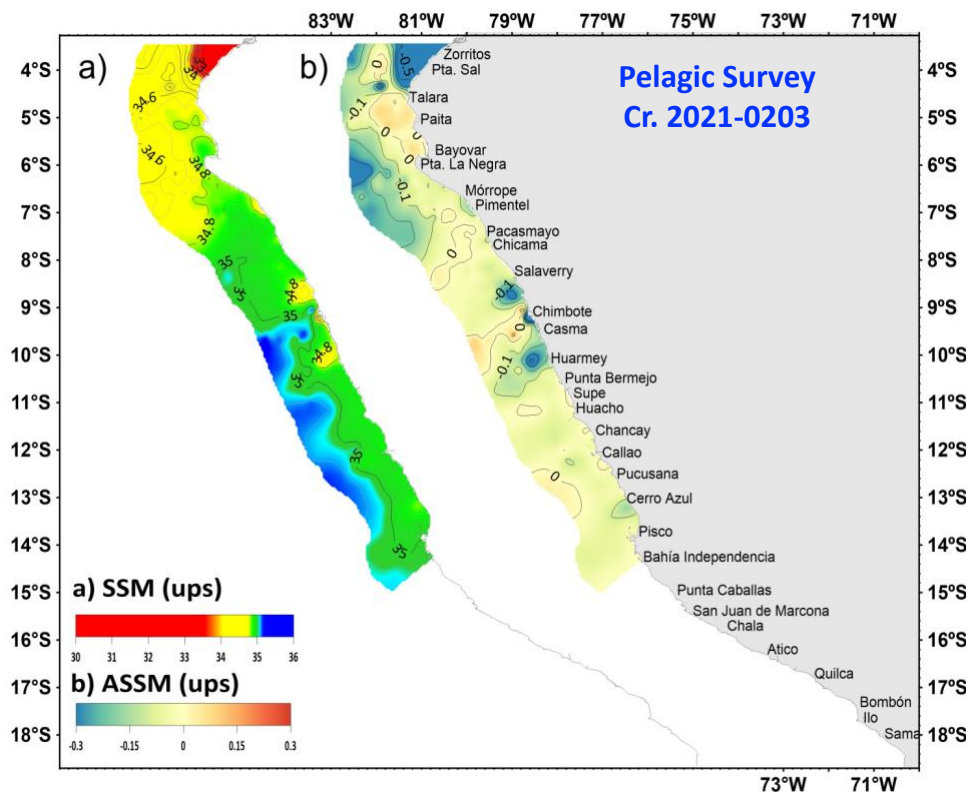


Figure 9.- Distribution of a) the sea surface salinity (SSS, in ups, left panel) and b) the anomaly of the sea surface salinity (SSSA, in ups, right panel) during summer (February-March) 2021, as observed during IMARPE's Hydroacoustic Survey for the Assessment of Pelagic Resources, Cr. 2021-0203, 17 February - 31 March 2021

During September-November 2020 the SSS fluctuated between 33.64 ups and 35.36 ups and together with the SSSA (Figure 8) show the presence of masses of subtropical surface waters from Salaverry to San Juan de Marcona beyond 50 nm distance from the coast, of cold coastal waters along a coastal band of variable amplitude between Chicama and San Juan de Marcona that widens significantly south of Callao and reaches the 100 nm from the coast off San Juan de Marcona. However, to the north, off Paita-Chicama, predominated mixed waters resulting from the interaction of subtropical surface waters and cold coastal waters, with the contribution of equatorial surface waters to the north of Paita. These types of mixed waters were also observed during an earlier research cruise, in August-September 2020. And during the September-November 2020 research cruise, cold conditions were observed in the water column down to 100 m depth, with much colder conditions in the first 50 m depth (of -1°C on average) from Callao to the north and (of -0.5°C) off Pisco and San Juan de Marcona. This cooling was caused by the arrival of several cold Kelvin waves and the coastal upwelling that remained active withing the 30 nm along the coast.

Then, by February-March 2021 (Figure 9), the SSS and the SSSA show that the intense intrusion of equatorial surface waters continued from the north, with presence as far south as Chicama and indirect influence a far south as Chimbote. The tropical surface waters (<34.0 ups) were located in coastal areas north of Punta Sal. The subtropical surface waters were limited to areas beyond 50 nm from the coast south of Huarmey, allowing an expansion of the areas covered by the cold coastal waters typical of the coastal upwelling. Also, strong mixing processes persisted north of Chimbote due to the interaction between equatorial surface waters, subtropical surface waters and cold coastal waters, as well as with waters from continental runoffs in areas adjacent to the river mouths. In general, saline concentrations were lower during summer 2021 than during summer 2020. This was favored by a reduced influence of the subtropical surface waters as well as by the arrival of several cold Kelvin waves and the sustained strength of the southeast trade winds that maintained a persistent coastal upwelling.

The cooling process that leaded to the development of the weak 2020 La Niña ended in May 2021 and it is expected that oceanographic conditions in the northern and central part of the Peruvian waters will remain, on average, within its normal ranges at least until September 2021, and that the coastal air temperatures will also remain, on average, within its normal ranges at least until September 2021 although a cooling process might be possible towards the end of the year (ENFEN, 2021)

3. CHARACTERIZATION OF THE STOCK

3.1. Spatial distribution

The alternating warmer and cooler than neutral environmental conditions that 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, while the prevalence of more extended periods of closer to neutral conditions in recent years have favored the presence of denser concentrations in late 2018 and, in particular, during 2019, 2020 and the first part of 2021.

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, where they were 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 those years 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, the closeness to the coast of the subtropical surface waters and the almost disappearance of the front of mixed subtropical surface waters with the 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, with an expansion as far north as Paita (5°00'S) closer to the coast during most of the second half of 2020. The cooler than neutral conditions during late 2020 and early 2021 cause most of the attractive commercial to be found to the south off Pisco (13°43'S).

3.2. Age and growth

The few age readings and length frequency distributions analyzed by the conventional methods between 2014 and early 2020 fall within the range of the growth parameters of the von Bertalanffy growth function in regular use by IMARPE, where: $L_{\infty} = 80.77$ cm total length, $k = 0.1553 \text{ y}^{-1}$ 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). No new age readings have been made during most of 2020 and first part of 2021 due to limitations to obtain otolith samples caused by the restrictions associated with the Covid-19 pandemic.

3.3. Reproductive aspects

The observed monthly variability of the gonadosomatic index (GSI) of Jack mackerel in Peruvian waters with respect to the 2002-2012 mean values taken as normal or standard (Figure 10), indicates that after the normal or slightly stronger than normal 2012-2013 reproductive cycle, the intensity of the reproduction process has been generally low until 2019-2020, while the 2020-2021 reproductive cycle has been much stronger than normal.

The monthly GSI values throughout most of 2018 and early 2019 were low and flat, placing the 2018-2019 reproductive cycle amongst the poorest on record. It is noted that this poor reproductive cycle falls right in between the weak-to-moderate 2017-2018 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 lower but very close to the long-term mean values and the 2020-2021 reproductive cycle has been better than normal, with GSI values during the key months of the cycle (September-December) consistently well above the long-term mean.

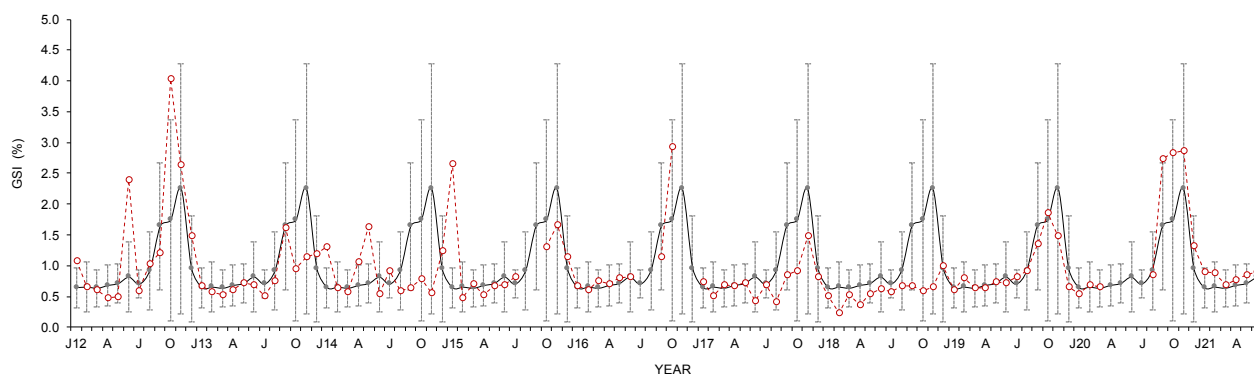


Figure 10.- Monthly variability of the Gonadosomatic Index (GSI) of Jack mackerel larger than 26 cm TL caught in Peruvian jurisdictional waters. The dark line and markers represent the long-term monthly mean for the years 2002-2012, taken as the standard and the grey vertical lines represent their respective standard deviations. The red circles and broken lines are the actual observed monthly values from January 2012 to June 2021. Updated from Perea *et al.* (2013)

As described above, the prevailing environmental conditions prior and during the main part (September-December) of this almost normal 2019-2020 reproductive cycle were neutral or very close to neutral. While during the main part of the stronger than normal 2020-2021 reproductive cycle the prevailing environmental conditions were between neutral and slightly cold.

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 species (95 preys in more than 60 taxa groups have been identified), although there has been a clear predominance of euphausiids.

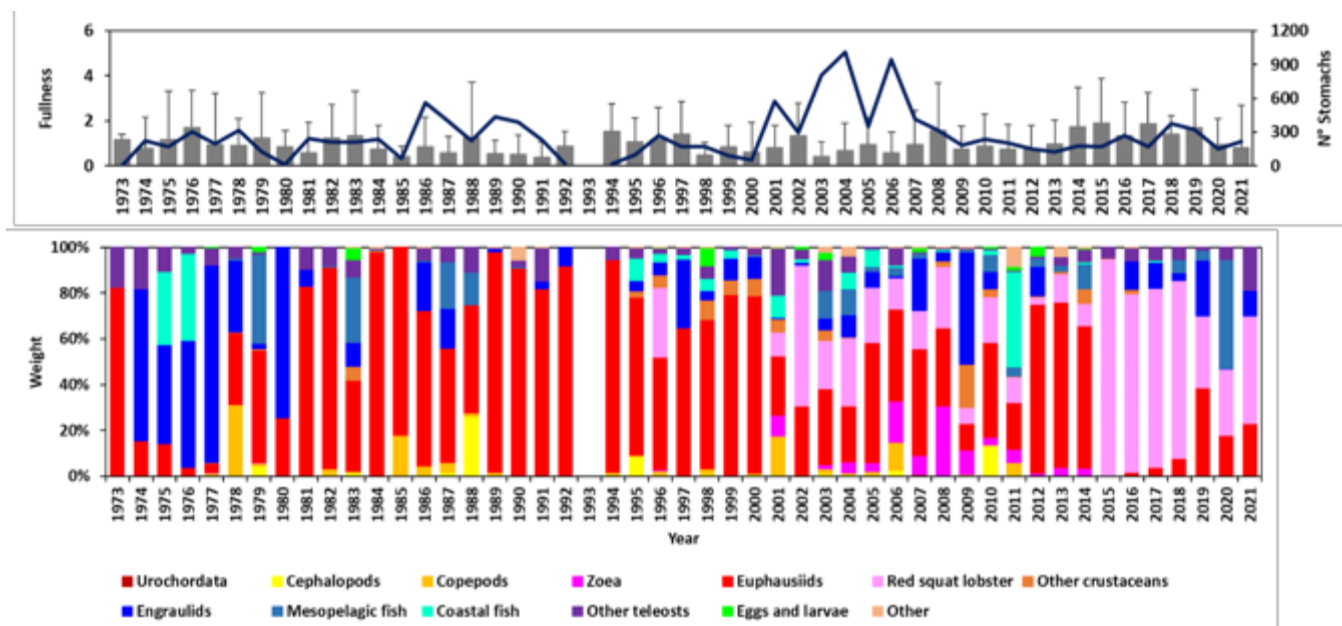


Figure 11.- Index of fullness (in %, vertical bars, top panel), sample size (solid lines, top panel) and proportion of preys (vertical bars, lower panel) in stomach content of Jack mackerel *Trachurus murphyi* off Peru from 1973 to 2021. Updated from Alegre *et al.* (2013, 2015)

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 red 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 red squat lobster in the diet of Jack mackerel since 2001, and particularly since 2015 is consistent with the noticeable increase in the abundance of red squat lobster observed off Peru since the late 1990s (Gutiérrez *et al.* 2008), while their clearer dominance during 2015-2018 (with percentages of 75-90% per year) might also be associated with the proximity to the coast of the subtropical subsurface waters between 10°S and 15°30'S and of the cold coastal waters from 16°S south, as well as with the more coastal distribution of most of the catches (and samples) taken in 2015-2018. This prey predominance changed in more recent years, with the increase in the proportions of euphausiids (39%) and engraulids (26%) with a lower proportion (31%) of red squat lobster in 2019; followed by still low proportion (28%) of red squat lobster and a much higher proportion (48%) of mesopelagic fish (mostly *Vinciguerria lucetia*) in 2020; and, the slight increase of red squat lobster (47%) and euphausiids (23%) followed by engraulids plus other teleosts (30%) in 2021. 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, 2020 and first part of 2021.

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 m³; and, the small-scale and artisanal fleets, with smaller 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 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 m³ 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.

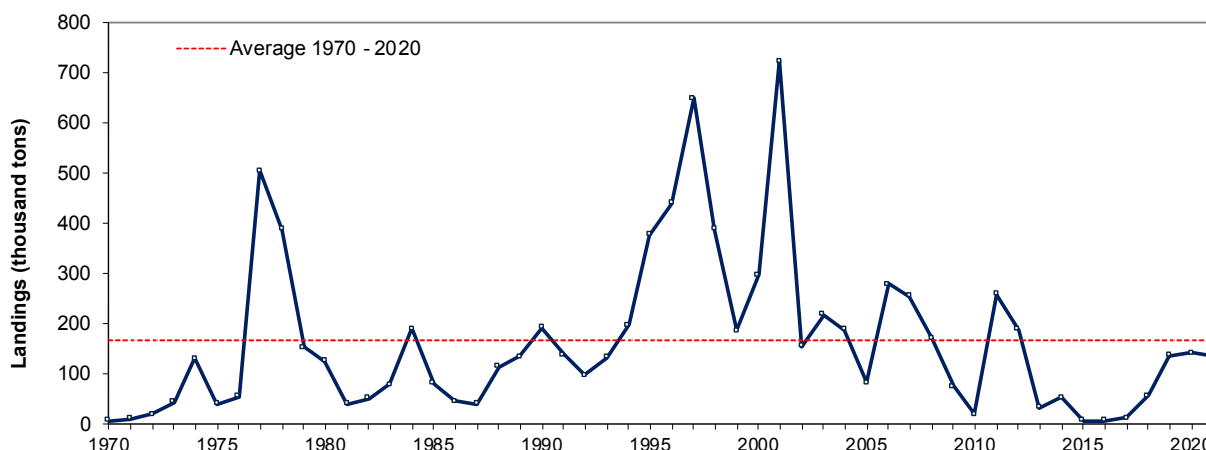


Figure 12.- Total annual landings of Jack mackerel (*Trachurus murphyi*) caught in Peruvian waters, years 1970-2020, plus January-June 2021

Catches during the first part of 2018 were also low but increased slightly during the second half of 2018 and had a clearer increase reaching much higher catches during 2019, which were maintained during 2020 and so far, the first half of 2021, getting close to, but still almost 15% under to the historic average for 1970-2020. 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 abundance and the 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 that can and are usually caught by this same fleet, such as anchoveta (*E. ringens*), chub mackerel (*S. japonicus*) and bonito (*S. chiliensis*). This resulted in that most of the catches of Jack mackerel that were reported during those years were those taken by smaller vessels of the artisanal and the small-scale purse seine fleets.

Towards the end of 2018 and throughout 2019 the availability and the total and monthly catches of Jack mackerel increased significantly with respect to the previous three years and, as shown in Figure 13, remained high during 2020 and the first part of 2021. These higher catches were mostly made by the industrial purse seine fleet during the relatively short fishing seasons during which this fleet is allowed to fish for and actually targets on

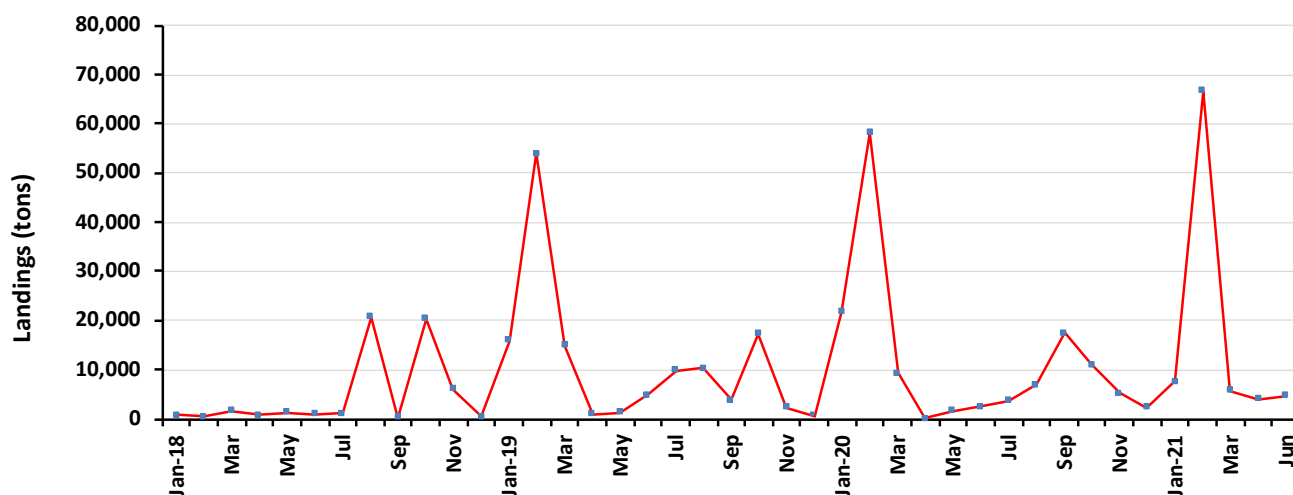


Figure 13.- Total monthly landings of Jack mackerel (*Trachurus murphyi*) caught in Peruvian waters, between January 2018 and June 2021

Jack mackerel since, as noted, when having the choice, part of this fleet may prefer to divert its attention to other species, such as anchoveta, chub mackerel or bonito. Conversely, the monthly catches of Jack mackerel by the artisanal and small-scale fleets are usually much lower and tend spread more evenly throughout the year, albeit with some fluctuations, mostly related to local market demand, seagoing weather conditions and availability of suitable Jack mackerel school concentrations in coastal areas.

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. Despite all of this, fishing for anchoveta 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 and 2021.

The above recent increase in monthly Jack mackerel catches during 2018 and 2019 and the continued high catches during 2020 and the first part of 2021 can also be explained by the increasing trend in CPUE abundance indexes from both the industrial and the group of artisanal and small-scale fleets, as shown in Figure 14. As can be noted, the monthly CPUE (in tons per trip) of both groups of fleets increased during the second half of 2018 and continue to increase, with some fluctuations, during the whole of 2019 and the beginning of 2020. Remaining at relative high levels with a generally increasing trend throughout June 2021.

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 and small-scale fleets are usually authorized to fish for Jack mackerel all year round. The artisanal and small-scale fleets also fish for other fishery resources which may or may not have seasonal closures.

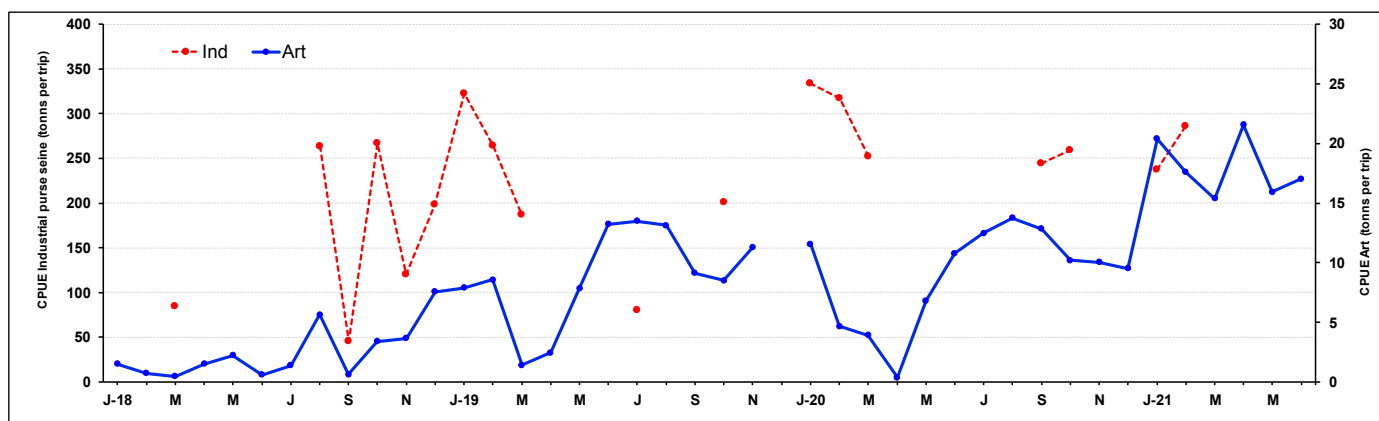


Figure 14.- Monthly catch per unit of effort (CPUE, in tons per trip) of Jack mackerel (*Trachurus murphyi*) by the industrial purse seine fleet (red dots and broken lines) and by the artisanal and small-scale purse seine fleets (blue dots and lines) fishing in Peruvian waters between January 2018 and June 2021

The 2018-2021 increase in the abundance of Jack mackerel illustrated by the CPUE values of both groups of 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 concentrations that are dispersed or forming dense schools close to the surface and, in addition, usually only cover areas within 60 to 100 nm distance from the coast, potentially missing important off-shore Jack mackerel concentrations. For instance, as reported in IMARPE-PRODUCE (2020), a recent pelagic stock assessment survey conducted by IMARPE from 15 February to 29 March 2020 only covered the first 90 nm distance from the coast, while most of the catches made during February-March 2020 by the industrial fleet came from fishing areas between 90 and 170 nm distance from the coast. But, even so, the observations made during this and other surveys have also shown a significant increase in the Jack mackerel acoustic abundance indices in late 2018 and 2019 and throughout 2020 and early 2021. 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

During 2020 the fishing areas of the artisanal and small-scale fleet fishing for Jack mackerel were widely distributed along the coast within 3 to 80 nm distance from the coastline, mainly between Huarmey (10°00'S) and Morro Sama (18°00'S). While the industrial purse seine fleet only fished for Jack mackerel during January and February and a few days in March, September and October 2020. The bulk of the 2020 catch of Jack mackerel by the industrial purse seine fleet was taken during the month of February 2020 in fishing areas located within 60 to 150 nm distance from the coast between San Juan de Marcona (15°22'S) and Morro Sama (Figure 15). The main fishing areas of the industrial purse seine fleet were mostly at around 60 nm from the coast off San Juan de Marcona in January 2020, almost 180 nm off Morro Sama in March, 60 nm off San Juan de Marcona in September and 60 nm off Morro Sama in October 2020 (Figure 5).

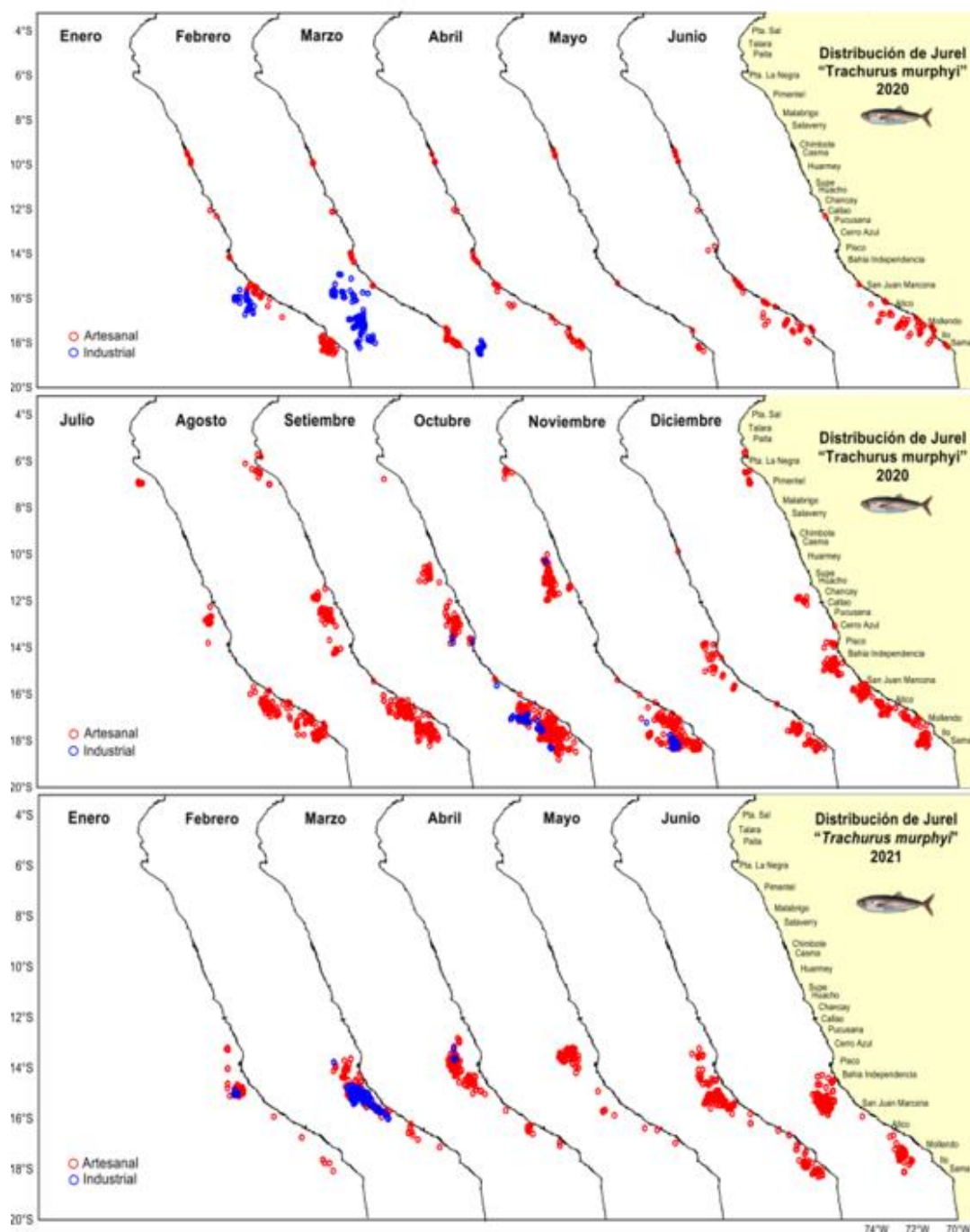


Figure 15.- Distribution of the Jack mackerel (*Trachurus murphyi*) fishing areas of the industrial purse seine fleet (blue circles) and by the artisanal and small-scale fleets (red triangles) fishing in Peruvian jurisdictional waters, by month, between January 2020 and June 2021

During the first part of 2021 all the fishing areas of Jack mackerel were located within 3 and 70 nm distance from the coast between Cerro Azul (13°00'S) and Morro Sama. Again, with the artisanal and small-scale fishing areas more widely distributed and the industrial fishing season and fishing areas mostly concentrated in February off San Juan de Marcona. The more southern distribution of the main fishing areas observed during January-June 2020 might be related to the cooler conditions observed during those months.

4.3. Size structure

The monthly size frequency distributions of Jack mackerel observed in the Peruvian fisheries by all fleets between January 2020 and June 2021 (Figure 16) continue to show that the fishery targets on a wide range of sizes of Jack mackerel, with unimodal or multimodal groups, and sizes ranging from 19 cm to 55 cm in total length (TL).

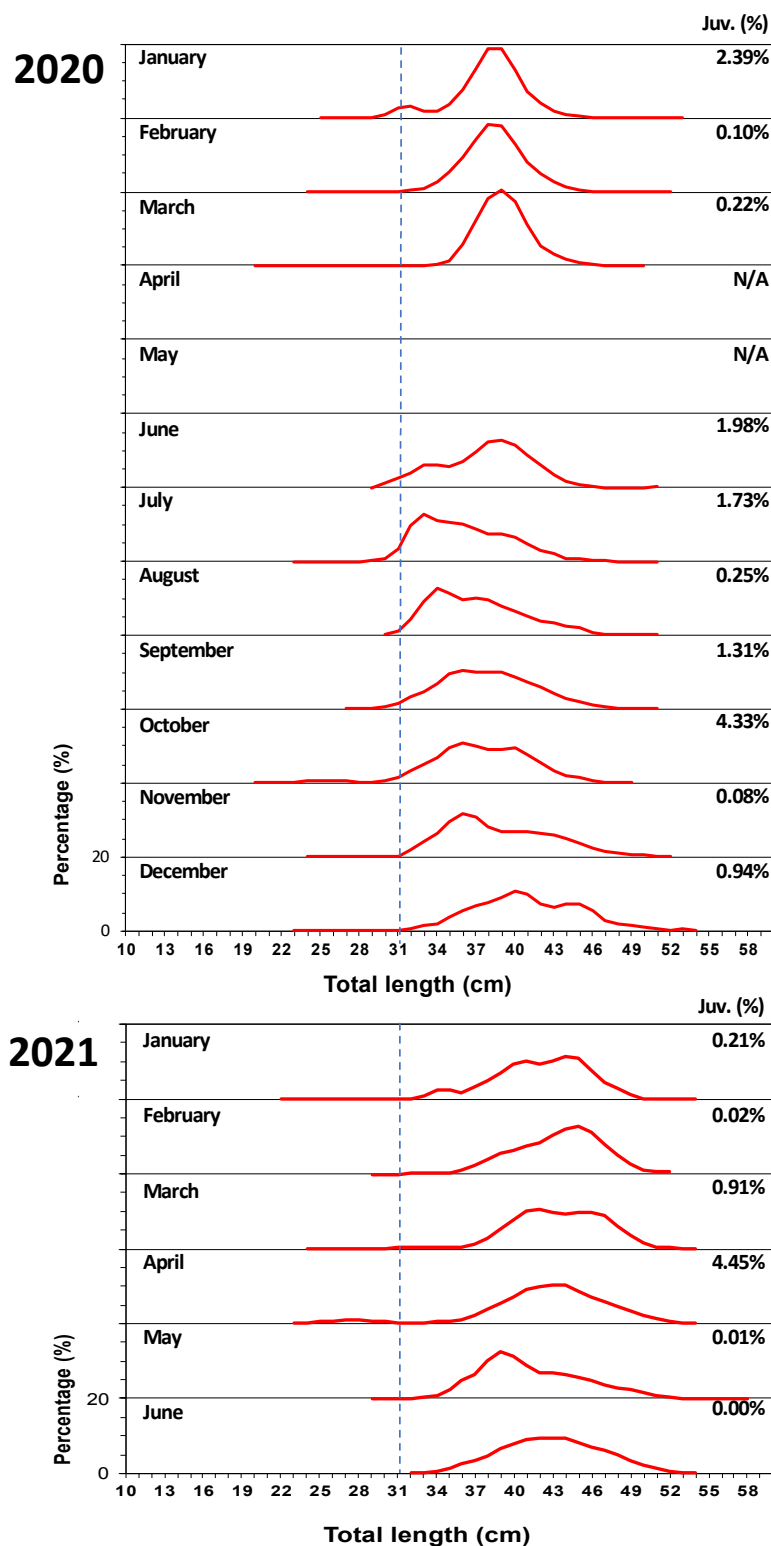


Figure 16.- Size frequency distribution of Jack mackerel (*Trachurus murphyi*) caught in Peruvian jurisdictional waters by the Peruvian artisanal, small-scale and industrial fleets, numbers by size in percentage by month, between January 2020 and June 2021

There was a fair presence of juveniles (fish smaller than 31.0 cm TL) in the commercial catches throughout most of the January 2020-June 2021 period, but this presence of juveniles was not as consisted as observed during 2019 and was far less than what was observed during 2018. Most of the catches during 2020 and 2021 were of adult Jack mackerels and the highest proportions of juveniles in numbers by month were observed in October 2020 (4.33%) and in April 2021 (4.45%). Due to the higher weight of the industrial purse seine fleet in the catch totals, the percentages shown in Figure 16 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, February, March, September and October 2020 and in January and February 2021. The size-frequency distributions of all the other months are those of the artisanal and small-scale vessels only. No size-frequency samples were taken during April and May 2020 due to Covid-19 related restrictions.

At least four main size groups were clearly visible in the commercial catches throughout 2020 and the first part of 2021, including: groups of juveniles smaller than 31 cm LT, with very low numbers but still visible almost every month observed; groups with modal sizes ranging from 32 to 36 cm TL, noticeable between January 2020 and January 2021 and

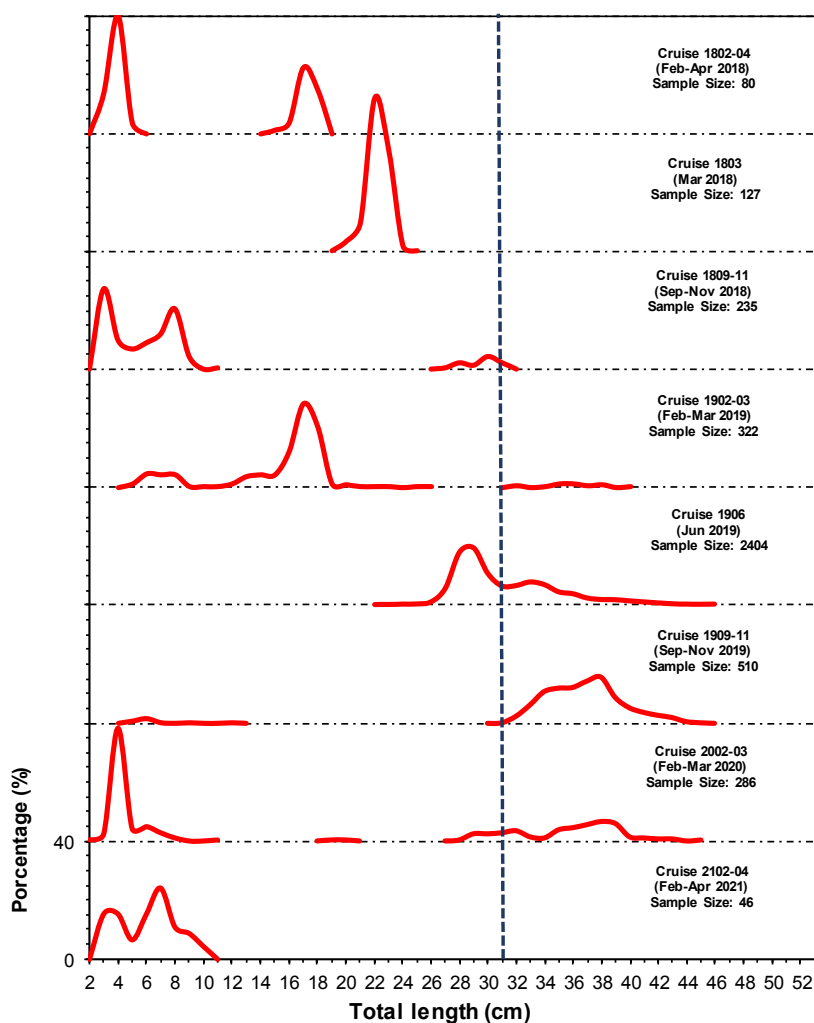


Figure 17.- Size-frequency distribution of Jack mackerel (*Trachurus murphyi*) caught in Peruvian jurisdictional waters during research surveys conducted by IMARPE between February 2018 and April 2021

particularly dominant between July and November 2020; groups with modal sizes ranging from 39 to 42 cm TL, noticeable during the whole period and particularly dominant between January-June 2020 and January-June 2021; and, groups with modal sizes in 44 and 45 cm TL, noticeable from December 2020 to June 2021 and particularly dominant in January-February 2021.

There was no great difference between the observed monthly size-frequency distributions of Jack mackerel caught by the artisanal and small-scale fleets and those caught by the industrial fleet, even though their main fishing areas were slightly different. Their main fishing areas of the industrial purse seine fleet were more or less within the same latitudes as the artisanal and small-scale fleets although much farther offshore in January-March 2020 and mostly within the same distance from the coast in October-November 2020 and January-March 2021 (as shown in Figure 15).

The research surveys conducted by IMARPE in 2018, 2019, 2020 and 2021 also found the large-size modal groups that were caught by the commercial fleets during the same years 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 TL (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 and their presence during the research surveys provide a valuable fishery-independent indication of the presence (although not in great abundance) of cohorts of early juveniles and pre-recruits, not yet available to the commercial fishery but soon to be recruited to the exploited stock.

The above 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 and completes its full life-cycle entirely in Peruvian waters, where it constitutes a unique biological and fishery unit, with most if not all the characteristics of a self-sustained stock unit.

5. STOCK ASSESSMENT

This section provides a brief summary of the late 2020 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 2021. This is followed by a 2021 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 2021.

5.1. 2020 assessment and 2021 TAC

In late December 2020 IMARPE updated the available 2020 Jack mackerel assessment that was produced earlier in October 2020 with data up to June 2020. This December 2020 assessment was made 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 2021 (IMARPE 2020) and was based on the latest version of the JJM model developed during the 8th meeting of the Scientific Committee held remotely from New Zealand from 3 to 8 October 2020 (SPRFMO 2020), but with all data and information updated to the end of December 2020.

The stock size estimated on January 1st 2021 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 2022 be lower than that estimated for January 1st 2021. Based on these exploitation scenarios, 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 2021 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 2020 advice to the Government on the prospects of the Peruvian Jack mackerel fishery for 2021, 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 2021 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, giving particular consideration to the possible continuation of the colder than neutral condition associated with the weak La Niña 2020.

Therefore, even if the observed environmental conditions were described as colder than neutral in December 2020, with prospects that colder conditions will continue for a few months, there was a certain degree of uncertainty on how the environmental conditions during 2021 would be like. 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 2020 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 2021 be established considering a multiplier of F_{2020} not exceeding 2.0, that corresponded to a maximum estimated $F = 0.077$ and a maximum projected TAC = 132 000 t, accepting a risk of 45.1% that the estimated biomass by January 1st 2022 be lower than that estimated for January 1st 2021.

Even if the observed CPUEs and the JJM biomass estimates showed clear positive trends over the past 3 years, the IMARPE advice noted and took into account some concerns regarding the low incidence of juveniles observed during the 2020 commercial catches and the low estimates of recent recruitment obtained with the JJM model; in addition to a certain level of uncertainty regarding the expected environmental conditions during 2021 and its effects on the distribution and local abundance of the jack mackerel schools concentrations.

The expectations were that the cooler than neutral conditions associated with the weak La Niña that started late in 2020 would have continued, at least during the first part of 2021, leading to the dispersal farther away from the coast of the jack mackerel concentrations due to the off-shore displacement of the front of mixed subtropical surface waters with the cold coastal waters, where Jack mackerel tends to concentrate. The expectations with regards to the effects of the environmental conditions during the second part of 2021 were, and to a certain degree are still a bit uncertain.

In its December 2020 advice IMARPE noted that, consequently, its maximum recommended F and TAC were set below those corresponding to the MSY, indicating 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 2020 assessment.

Based on this advice, on 19 January 2021 PRODUCE established a catch limit of 65 410 t for the Jack mackerel (*Trachurus murphyi*) to be caught in Peruvian jurisdictional waters by the large-scale or industrial fleet during 2021, which was divided into 33 410 t as a direct allocation and 32 000 t as a reserve to cover the possible incidence of Jack mackerel as by-catch in the chub mackerel (*Scomber japonicus*) fishery (ref.: R.M. 016-2021-PRODUCE). Based on their regular low catches throughout the year and other socio-economic and legal considerations, no catch limit has been established for the Jack mackerel fishery by artisanal and small-scale vessels. Nevertheless, the preamble and recitals of the Produce resolution clearly indicate the intention to opt for a total catch limit of 101 000 t, corresponding to the intermediate reference level recommended by IMARPE. The above TAC = 101 000 t corresponds to a multiplier of $F_{2020} = 1.50$ and an estimated $F_{2021} = 0.048$ according to IMARPE's December 2020 assessment.

As advised by IMARPE, 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.

5.2. 2021 assessment

The main purpose of this latest 2021 assessment is to update the JJM model estimates with the most recent data and information up to June 2021, but with estimated total catch projected to December 2021, using the same configurations of the 2020 JJM model developed during the 8th meeting of the Scientific Committee in October 2020 and used in IMARPE's late December 2020 advice.

5.2.1. Updated information used in the 2021 assessment

Information about catch, catch at length, catch at age and weight at age were updated to June 2021, with estimated total catch projected to December 2021. 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. Yearly 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 2002-2021 (Figure 18).

It is noted that the updated 2021 CPUE (updated to June 2021) is much higher than the 2020 CPUE, which is also a bit higher than the 2019 CPUE. This is consistent with the increasing trend in monthly CPUE indexes from both industrial fleet and particularly from

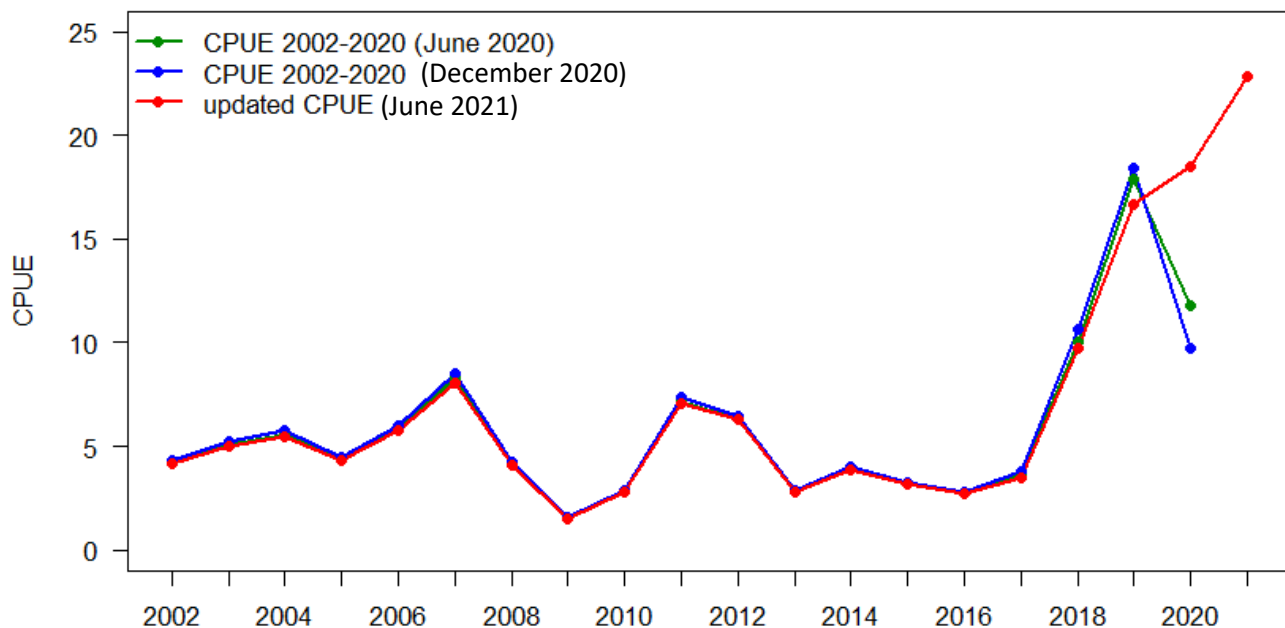


Figure 18.- Updated CPUE time series of Jack mackerel *Trachurus murphyi* caught in Peruvian jurisdictional waters by the industrial and the artisanal and small-scale fleets between 2002 and 2021

the group of artisanal and small-scale fleets since 2018, as shown in Figure 14. It is also noted that the 2020 CPUEs estimated in June 2020 and in December 2020 are much lower than the 2020 CPUE estimated with this recent June 2021 update. This is because the June 2021 update included the complete data from the industrial and artisanal and small-scale fisheries up to June 2021, while the December 2020 update included the complete data from the industrial fleet and only partial and/or incomplete data from the artisanal and small-scale fleets for the second semester of 2020, which were much higher than during the first semester. Neither of the higher monthly CPUEs observed during the second semester of 2020 were represented in the June 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 noted that the

coastal cooling and stronger upwelling associated with the weak-to-moderate La Niña in late 2017 to early 2018 have caused the dispersal farther offshore, beyond the surveyed areas, of most of the good concentrations of Jack mackerel. The more recent pelagic stock assessment research surveys have also covered undetermined fractions of the total distribution of Jack mackerel in Peruvian waters, and, therefore, there is no updating of the echo-abundance index in the current 2021 JJM assessment.

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 2021 assessment of the Peruvian (far-north) Jack mackerel

Type	Data	Details
From the fishery	Catch	1970 – 2021
	Catch-at-length	1980 – 2021
	Catch-at-age	1980 – 2021
	CPUE	2002 – 2021
	Selectivity	Dome shaped
Fishery independent	Echo-abundance	1985 – 2014
	Selectivity	Logistic
Biological	Growth parameters	$k=0.165 \text{ y}^{-1}$, $L_{\infty}=80.4 \text{ cm}$
	Natural mortality	$M=0.33$
	Maturity at age	First maturity=2 years
	Weight at age	From updated W-L parameters

5.2.2. 2021 Joint Jack Mackerel (JJM) model

The same configurations of the 2020 assessment were implemented in the 2021 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.

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 higher values of biomass at the beginning of the series and slightly higher values of biomass at the end (last 3 years) 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, with configurations 1.1 and 1.2 producing slightly lower values of biomass at the beginning of the series but very similar values of biomass throughout the middle and the end of the series (Figure 19d).

Table 2.- Model configurations implemented in the 2021 JJM assessment of the Peruvian (far-north) Jack mackerel stock

Model	Description
Data update	
0.0	- As 2020 configuration and data - Indices: <i>echo-abundance</i> (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 2021
0.2	As in model 0.1 but with updated CPUE (2002-2021)
0.3	As in model 0.2 but with updated mean weight at age (2013-2021)
Model configuration	
1.0	As in model 0.3 (steepness = 0.65)
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 2020 to scale with two regimes

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 between 2000 and at least 2018, with an intermediate stage or possible temporary shift in 2019-2021. These two regimes described by the JJM model are consistent with the observed decadal regime changes in the marine 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). And, as pointed out by Arguelles *et al.* (2019) for the case of the jumbo flying squid (*Dosidicus gigas*), the increased abundance and higher biomass estimates of Jack mackerel in the recent 2-3 years could be just a temporary biomass burst, but it could also be an indication that a regime shift (to higher abundance) is in the making, whose expected magnitude and duration are, in any case, great uncertainties worth looking into in future analyses.

The mean value of fishing mortality estimated for years between 1970 and 2021 was very similar for the seven configurations, as well as their distributions (Figures 19b and 19d). And the outputs of the final configuration show an increase in the biomass of 2021 with respect to the biomass of 2020 and, in general, a continuing increasing trend of the estimated biomass since 2016.

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 noted early, the stock would have passed through two stages of productivity, or regimes, with high levels of total biomass during the 1990s and low levels since 2000, with an intermediate stage and so far, temporary shift to higher abundance levels since 2019. These two main stages are represented by two stock-recruitment regimes (Figure 20, lower panel). With one high productivity regime from 1970 to 1996 and a lower

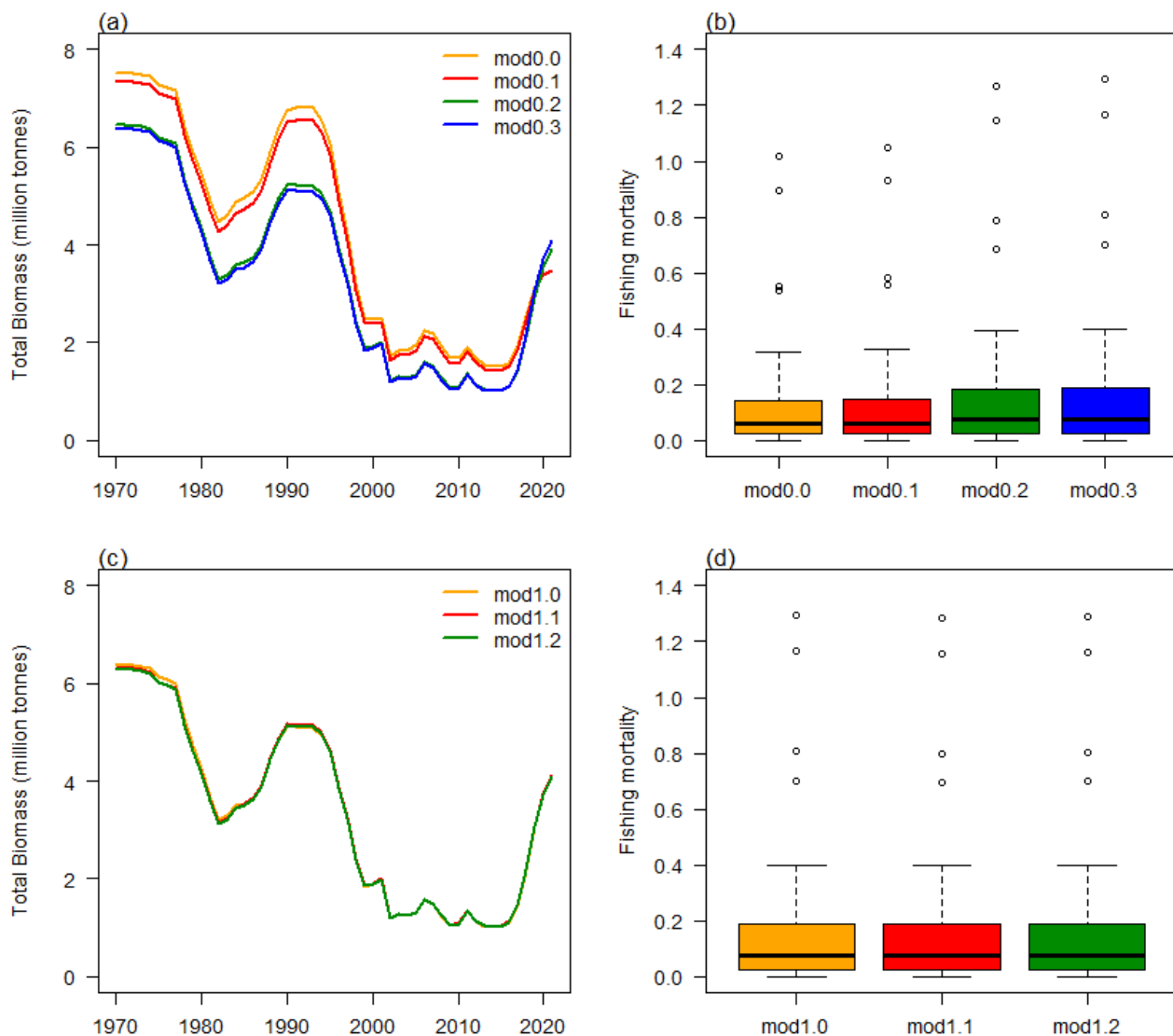


Figure 19.- Main outputs for the group 0 (top panel - testing the sensitivity to updated data) and group 1 (bottom panel - testing the sensitivity to assumptions on recruitment productivity) model configurations of the 2021 assessment with the Joint Jack Mackerel (JJM) model, where: (a) total biomass 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

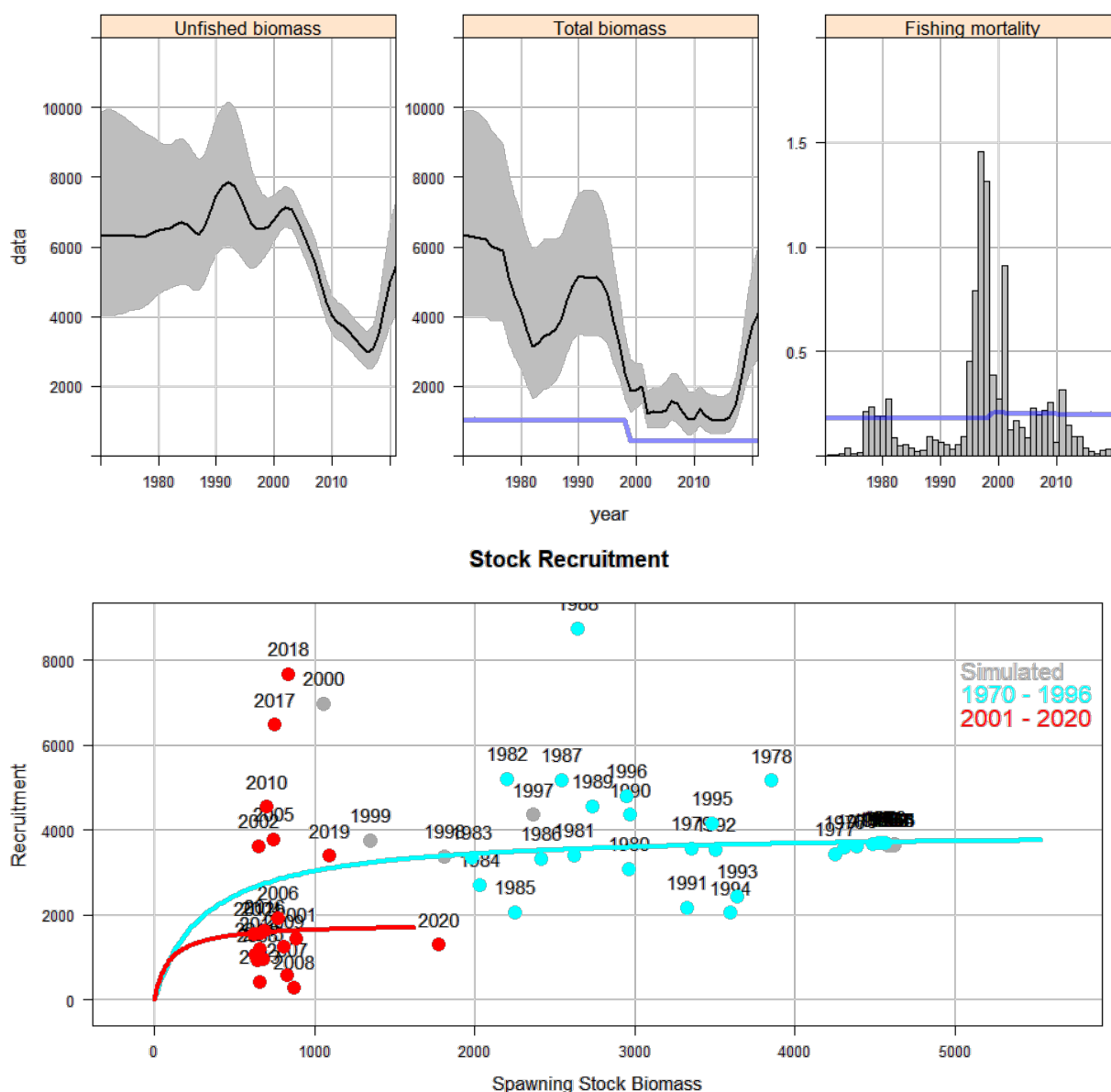


Figure 20.- Outputs of the final configuration of the JJM model showing the history and current situation of the Peruvian (far-north) stock of Jack mackerel (*Trachurus murphyi*). Unfished biomass and total biomass (in thousand t) and yearly fishing mortality are presented at the top panels. The stock-recruitment relationship showing two regimes is presented in the lower panel. 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).

productivity regime from 2001 to 2020. Although, as noted earlier, the consistent increasing trend in the last 2-3 years is worth further consideration from this “regime” perspective. 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 presumed current low abundance regime, and would still be well above the MSY levels if a higher abundance regime is assumed. Nevertheless, even if the stock appears to be in good health and the biomass estimates are high and show a continuing increasing trend in the recent 2-3 years, there is a need to be precautionary and follow-up on, and pay attention to the low future recruitments predicted by the JJM model based on the stock-recruitment relationship mean curve for the low abundance regime (Figure 20) and to the low incidence of juveniles observed in the commercial catches during the second half of 2019, the whole of 2020 and the first part of 2021. As well as to the low recent recruitments estimated by the JJM model, and the uncertainties regarding future environmental conditions. On this, it is also noted that the estimates and projections of biomass and other variables obtained with the JJM also show the great variability of past recruitments and reaffirm 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, recruitment, etc., of Jack mackerel in Peruvian waters.

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