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IMARPE - 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

by

IMARPE - PRODUCE

2017

SUMMARY

This report updates information on the biology and fishery of jack mackerel (*Trachurus murphyi*) in Peru presented in previous SPRFMO Scientific Committee meeting reports. During 2014, 2015, 2016 and the first part of 2017 the Peruvian coastal areas have been affected by warmer than normal conditions typical of a weak El Niño during 2014, a strong El Niño during 2015 and 2016, and a moderate coastal El Niño in early 2017. With these warmer than normal environmental conditions the front usually formed by the mixed layer of warm Subtropical Surface Waters and Cold Coastal Waters almost disappeared and moved closer to the coast, disrupting what is known to be the preferred habitat of jack mackerel off Peru. This contributed to low observed abundance and low catches of jack mackerel in 2014 and particularly in 2015, 2016 and the first part of 2017. During these years jack mackerel concentrations were mostly found in coastal areas, within 20 nm and sometimes within 10 nm from the coast, within reach of the artisanal and small scale fleets but outside of the usual fishing grounds of the industrial purse seine fleet. In December 2016 the Peruvian Institute of Marine Research (IMARPE) updated the available 2016 jack mackerel assessment made for the Peruvian (far-north) stock during the SC-04 to estimate a TAC for 2017, using the same latest version of the JJM model. This resulted in an estimated TAC of 107 000 t and an F_{2017} = 0.045 with an estimated risk of 15.5% that the biomass projected to January 1st 2018 will be lower than that estimated for January 2017.

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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; Csirke *et al*. 2013).

Warmer than normal conditions have dominated the marine environment off Peru since 2014. There was a weak El Niño in mid 2014, a strong El Niño during 2015 and the first half of 2016, and a moderate coastal El Niño from December 2016 to May 2017. As explained below, these warmer than normal environmental conditions contributed to the low observed abundance indexes and low catches of jack mackerel (*Trachurus murphyi*) in Peruvian jurisdictional waters in 2014 and particularly in 2015, 2016 and so far, the first part of 2017.

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 from April 2015 to April 2016. This was followed by a short period of warm but close to neutral conditions and an unexpected warming described as a coastal El Niño from late December 2016 to May 2017. This sequence of events and the difference between the more regional 2014 and 2015-2016 El Niños and the 2017 coastal El Niño are described by: the monthly thermal anomalies (°C) based on the Coastal Index of El Niño (ICEN) in the El Niño 1+2 region (Figure 1); the equivalent but more coastal index

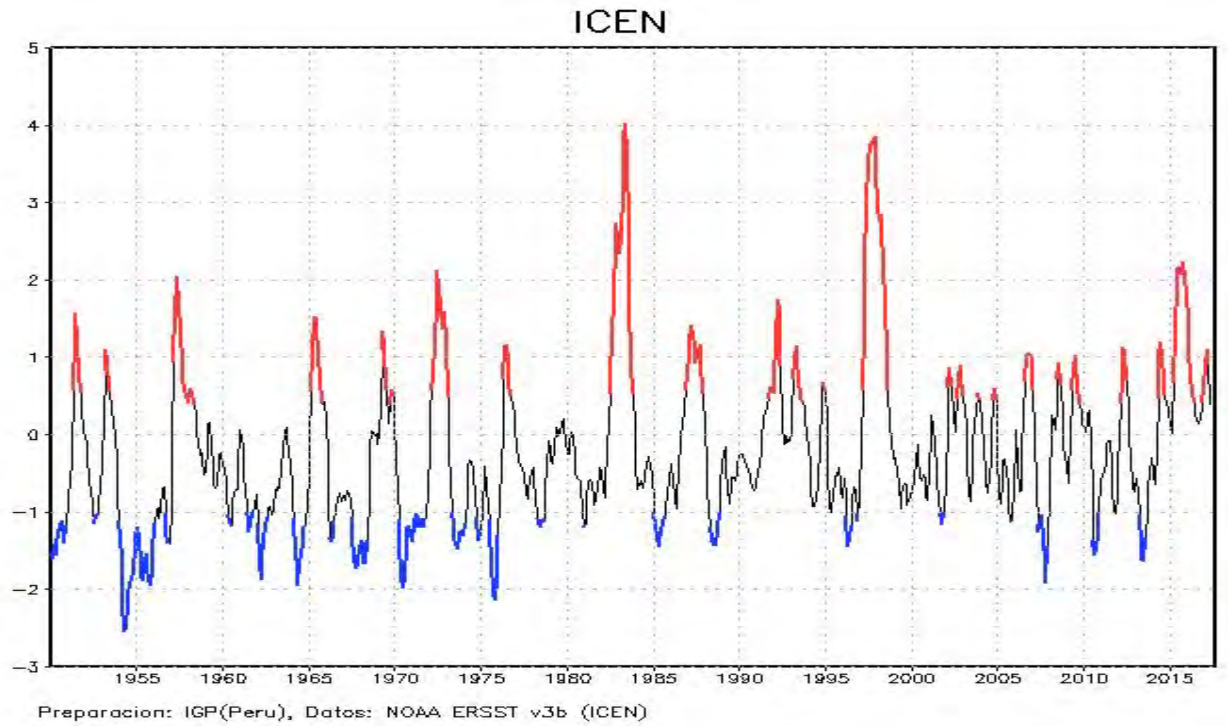


Figure 1.- Coastal Index of El Niño (ICEN) in the El Niño 1+2 region, by month, from January 1950 to June 2017. Calculated as the 3-month moving average of the anomalies of the sea surface temperature in the Niño 1+2 region, referred to a 30-year (1981-2010) monthly mean pattern. El Niño conditions are highlighted in red and La Niña conditions are highlighted in blue (data source: NOAA ERSST - ICEN)

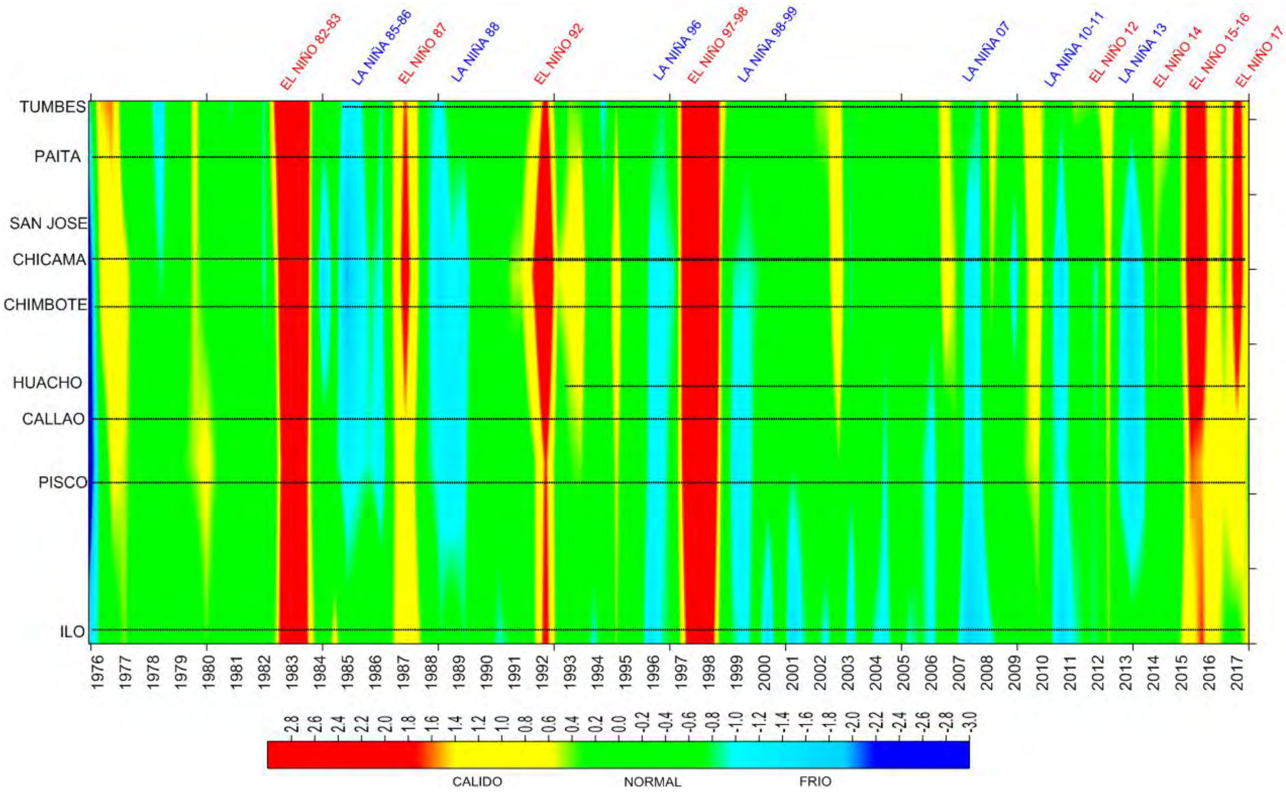
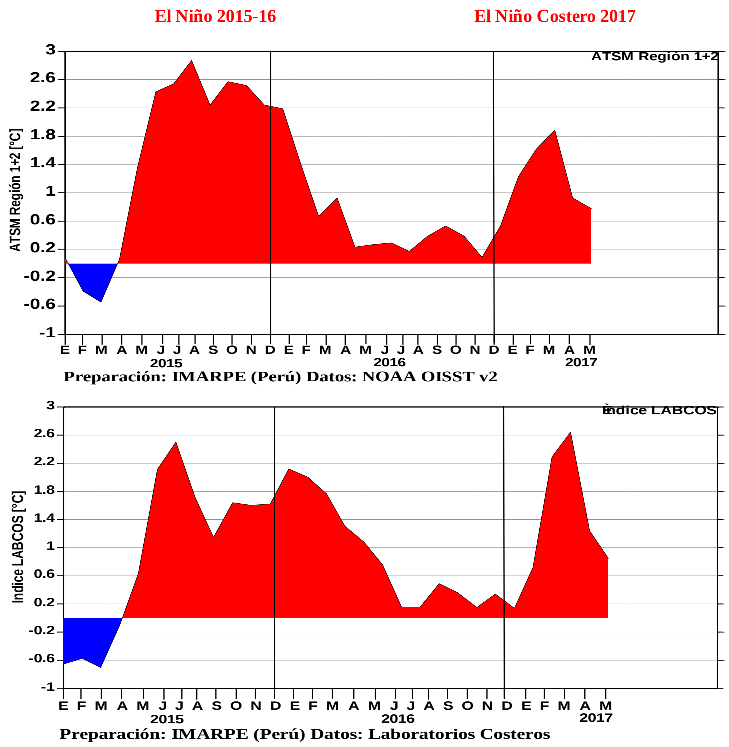


Figure 2.- Sea Surface Temperature Anomalies (SSTA, in °C) from IMARPE´s coastal laboratories and stations, by latitude along the entire Peruvian coast, years 1976–2017 (until June 2017) (data source: IMARPE)

developed by IMARPE on the basis of its own sea surface temperature records provided by its network of coastal laboratories and marine stations along the whole Peruvian coast (Figure 2); and, the more detailed data on sea surface temperature (SST) and sea surface salinity (SSS) during a selected 2-month period (March-April 2017) along the Peruvian coast, which follow.

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 is described as a strong one, following in strength the latest two very strong El Niños of 1982-1983 and 1997-1998. The 1982-1983 and 1997-1998 El Niños had stronger and longer lasting effects along the whole Peruvian coast, while the 2015-2016 El Niño was shorter and even if its effects were also noted along the whole Peruvian coast its strongest effects were felt north of Callao (12°02'S). It is noteworthy that, although it may not be evident from the ICEN or the more coastal IMARPE indices in Figures 1 and 2, 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.

During the strong 2015-2016 El Niño, the positive anomalies of the sea surface temperature (SSTA) in the Niño 1+2 region were noticeable since May 2015 and remain consistently above +0.5°C throughout April 2016, with a maximum SSTA of +2.8°C in July 2015 and values above +2.2 throughout the end of 2015. The anomalies then declined rapidly between January and April 2016, tending to stabilize at positive but more neutral values below +0.5 °C between May and November 2016. Then the SSTA in the Niño 1+2 region increased rapidly during the development of the moderate 2017 coastal El Niño, reaching a maximum monthly anomaly of +1.9°C in March 2017, declining to +0.8 by May 2017 (Figure 3, top panel).



YEAR	MONTH	SSTA Region 1+2	IMARPE Labcos Index
2017	January	1.23	0.72
2017	February	1.62	2.29
2017	March	1.89	2.64
2017	April	0.93	1.24
2017	May	0.78	0.85

Figure 3.- Mean monthly sea surface temperature anomalies (SSTA, in °C) in the coastal Niño 1+2 region (SSTA Niño 1+2 region - top panel) and along the Peruvian coastline (LABCOS index - bottom panel) from January 2015 to March 2017, with detailed monthly values for January-May 2017 (right table)

During the same period, the more coastal index (LABCOS index) based on the IMARPE records from its own coastal laboratories and marine stations describe the more coastal evolution of these two El Niño (Figure 3, bottom panel). Positive SSTA values are also noticeable in the coastal (LABCOS) index since May 2015, reaching a maximum of +2.5°C in June 2015, to decline to +1.2°C in September 2015 and increase again peaking at +2.0°C by January 2016. Declining with the end of the 2015-2016 El Niño to more neutral values below +0.5°C from June throughout December 2016. The SSTA then increased rapidly with the development of the 2017 coastal El Niño in January 2017, reaching a maximum value of +2.6°C in March 2017, to then decline to +0.8°C in May 2017.

The comparison of the two SSTA series in Figure 3 clearly shows that during the strong 2015-16 El Niño, the anomalies in the Niño 1+2 region were consistently higher than along the Peruvian coast; while during the moderate 2017 coastal El Niño, the SSTA along the Peruvian coastline were higher, with a maximum of +2.6 in March 2017. This is consistent with how the effects of these two El Niño were perceived coastal marine and inland areas north of Callao.

Between March and April 2017, the SST measurements made by IMARPE's Pelagic Resources Assessment Survey 1703-04 off the Peruvian coast varied from 16.1 to 27.9°C, with values higher than 27°C as close as 30nm between Salaverry (8°13'S) and Casma (9°28'S). SST values lower than 20°C associated with upwelling processes were located 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) (Figure 4, left panel). The thermal distribution showed a predominance of warm conditions to the north of Punta Caballas (14°56'S), with SSTA of up to +6°C off Chimbote (09°04'S) and with SSTA higher than +3°C very close to the coast between 8°S and 11°S and

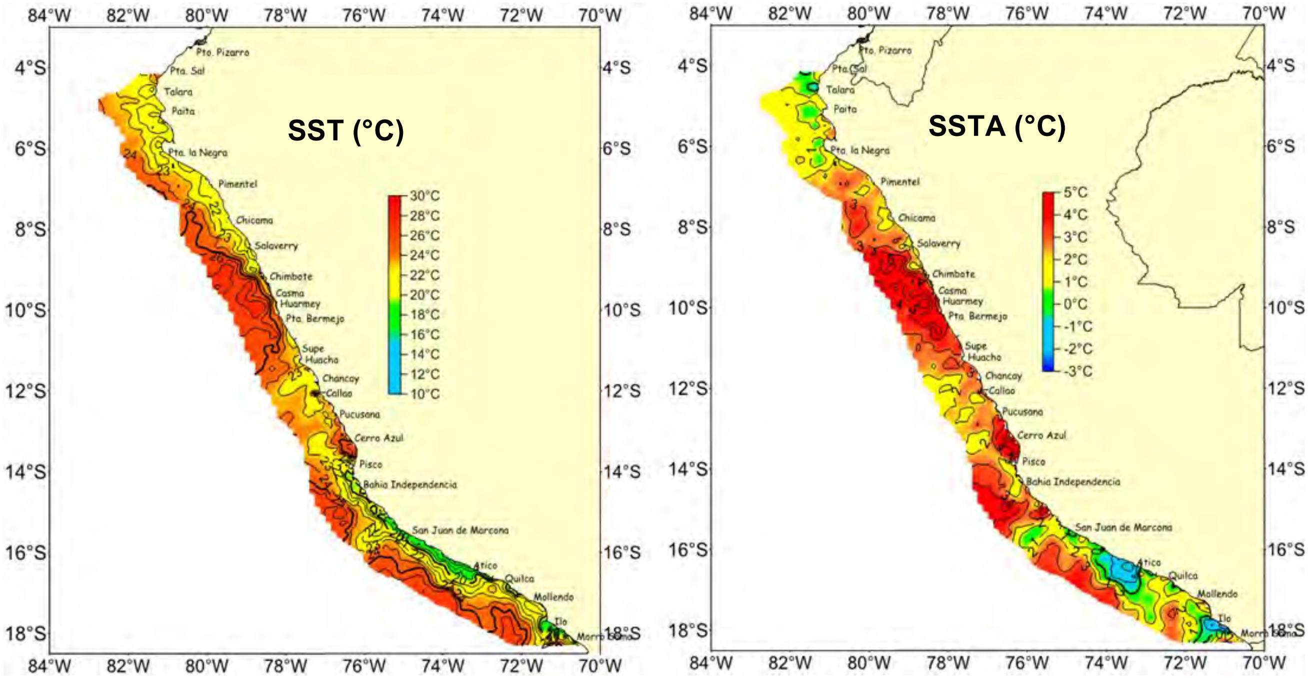


Figure 4.- Distribution of the sea surface temperature (SST, in °C, left panel) and sea surface temperature anomalies (SSTA, in °C, right panel) during March and April 2017, as measured by IMARPE's Pelagic Resources Assessment Survey Cr. 1703-04

between 13°S and 15°S, and farther than 30 nm from the coast south of 15°S. With negative anomalies to the south of 16°S, were there was a coastal area with negative SSTA as low as -2°C off Atico (16°13'S) (Figure 4, right panel).

The spatial distribution of the sea surface salinity (SSS) (Figure 5, left panel) in relation to the SST during March-April 2017 indicate the presence of Tropical Surface Waters (TSW/ATS) north of Talara (4°35'S), Equatorial Surface Waters (ESW/AES) unusually

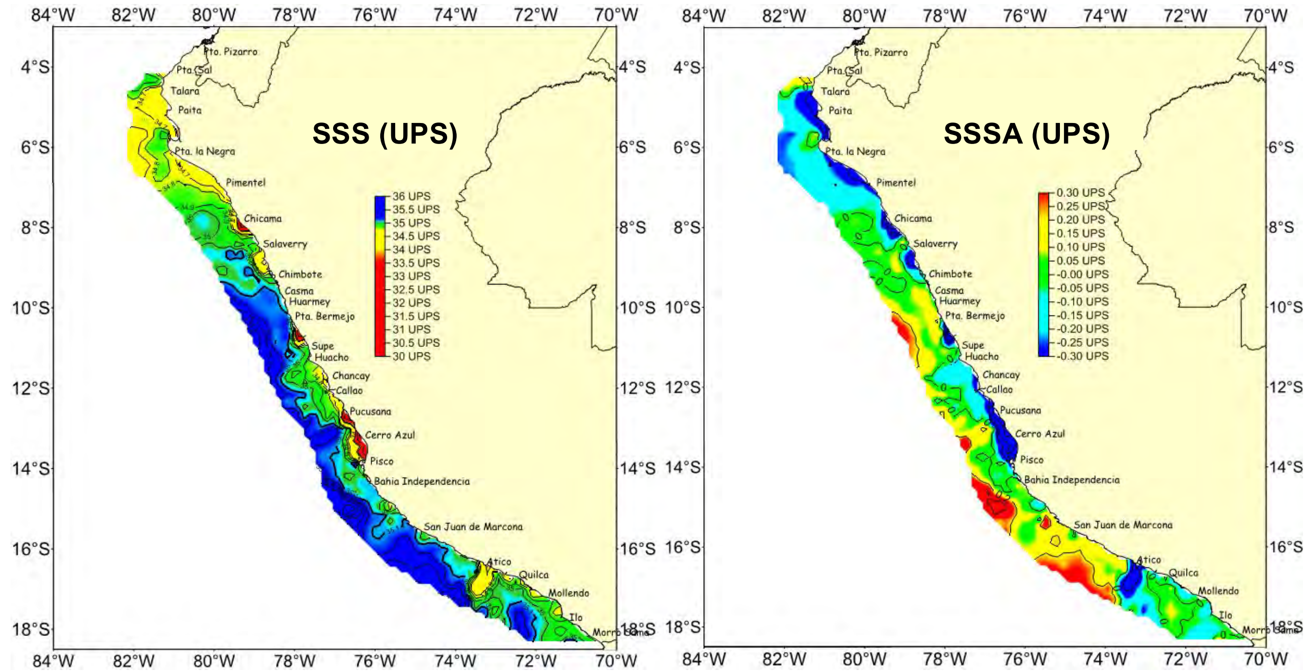


Figure 5.- Distribution of the sea surface salinity (SSS, in UPS, left panel) and the anomaly of the sea surface salinity (SSSA, in UPS, right panel) during March and April 2017, as measured by IMARPE's Pelagic Resources Assessment Survey Cr. 1703-04

displaced as far south as Chimbote (09°04'S) and Subtropical Surface Waters (SSW/ASS) to the south of Chimbote, getting very close to the coast at 10°S and 15°30'S. The Cold Coastal Waters (CCW/ACF) were restricted to a narrow area to the south of 16°S, of no more than 30mn from the coast.

On the other hand, the mixing processes in the coastal zones were noticeable due to the augmented river discharges associated with the increased precipitation caused by the 2017 coastal El Niño, and to the interaction between ESW/AES and SSW/ASS in the northern zone and between the SSW/ASS and CCW/ACF in the south-central zone. The positive anomalies of the sea surface salinity (SSSA) covered around 80% of the surveyed area during March-April 2017 (Figure 5, right panel), mostly due to the presence of SSW/ASS, while negative anomalies were associated with the presence of ESW/AES and were located mainly to the north of Chimbote, between Callao and Pisco and off Atico, in coastal areas with a high discharge of fresh water from the continent.

3. CHARACTERIZATION OF THE STOCK

This section provides a brief update on the main biological and behavioral observations reported in last year's report (IMARPE-PRODUCE 2016).

3.1. Spatial distribution

The warmer environmental conditions that have prevailed along the Peruvian coast due to the weak to moderate 2014 El Niño, the strong 2015-2016 El Niño and the moderate coastal 2017 El Niño has caused a more or less persistent displacement and possibly a dispersion of the jack mackerel concentrations. 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 20 nm and frequently within 10 nm from the coast, within reach of the artisanal and small scale fleet but outside the reach and usual fishing grounds of the industrial purse seine fleet. This change in the spatial distribution of jack mackerel in 2014 and particularly during 2015, 2016 and early 2017 is closely related to the closeness to the coast of the Subtropical Surface Waters and the almost disappearance of the mixed layer with Cold Coastal Waters caused by the strong 2015-16 El Niño and the moderate 2017 coastal El Niño.

3.2. Age and growth

The few age readings and length frequency distributions analyzed by the conventional methods between 2014-2017 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.

Some limited readings of microincrements in otoliths of jack mackerels sampled during 2015 and 2016 are underway, trying to determine if there are changes in growth pattern associated with El Niño that may not be all that noticeable through the more conventional annual ring readings.

3.3. Reproductive aspects

During the 2013-2014 and 2014-2015 reproductive cycles the intensity of the reproduction process was low and out of phase with respect to the 2002-2012 mean values taken as standard, and continued to be low throughout 2017 (Figure 6).

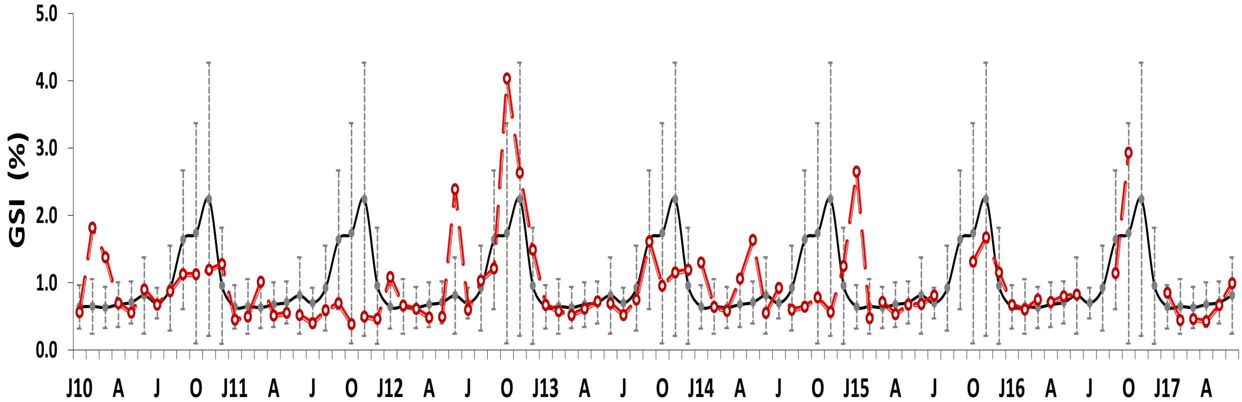


Figure 6.- Monthly variability of the Gonadosomatic Index of jack mackerel in Peruvian jurisdictional waters. The dark line and markers represent the long-term monthly mean for the years 2002-2012 taken as the standard and the grey vertical lines their respective standard deviations. The red circles and broken lines are the actual observed monthly values from January 2010 to June 2017. Updated from Perea et al (2013)

3.4. Trophic relationships

The updated information on food content based on the work by Alegre *et al*. (2013, 2015) confirms jack mackerel as 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). There is a great diversity of preys in the diet of jack mackerel off Peru. Reportedly it forages on a large variety of taxa (60+ prey taxa), although during most of the last 45 years there has bee a clear predominance of euphausids (Figure 7). The stronger dominance of euphausids in the diet of jack mackerel was observed during the warmer period of 1973 to 2000, while a more diversified diet is observed during the more recent slightly colder period of 2001 to 2014. During these slightly colder years euphausids continue to be an important

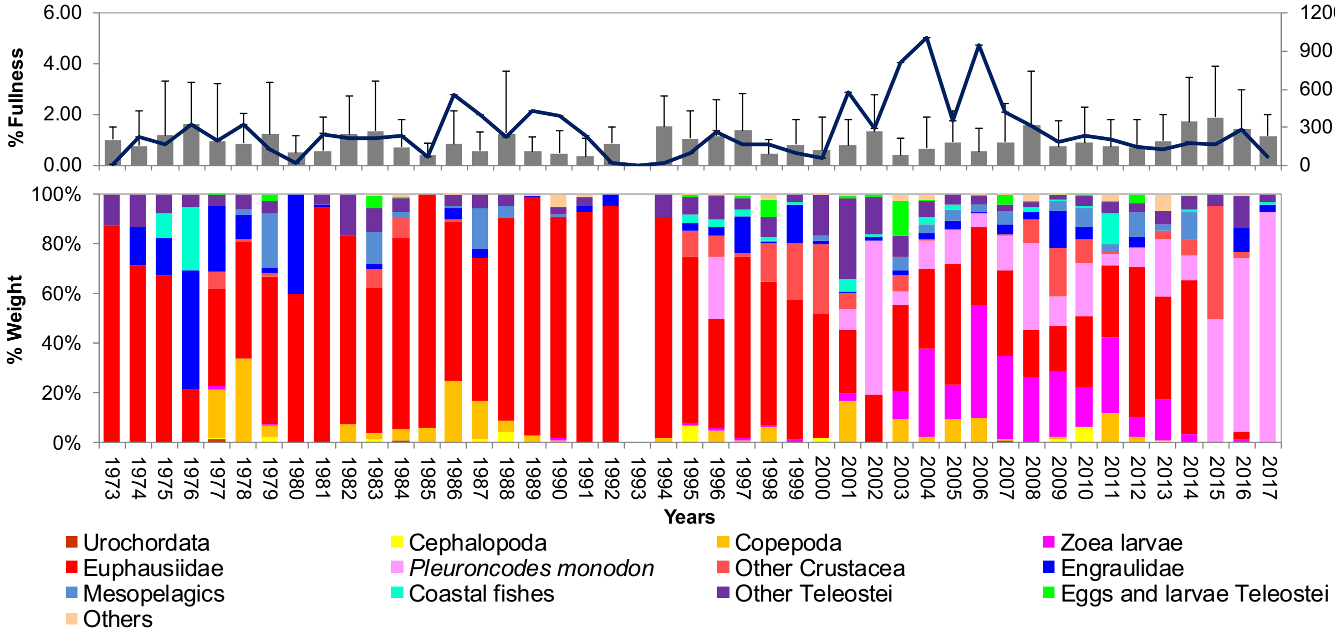


Figure 7.- Index of fullness (in %, vertical bars, top panel), sample size (solid lines, top panel) and proportion of preys (vertical bars, lower panel) in stomach content of jack mackerel *Trachurus murphyi* off Peru from 1973 to 2017 (January-June 2017 only). Updated from Alegre et al. (2013, 2015)

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, 2016 and 2017, under 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 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/ASS) at 10°S and 15°30'S and of the Cold Coastal Waters (CCW/ACF) from 16°S to the south and the very coastal distribution of most of the catches and samples taken in 2015-2017.

4. DESCRIPTION OF THE FISHERY

Due to lower catches of jack mackerel and the increase in catches of other species, as it occurred in 2015, in 2016 jack mackerel remain in the seventh position, being preceded (in order of importance by catch volumes) by: anchoveta (*Engraulis ringens*), jumbo squid (*Dosidicus gigas*), bonito (*Sarda chiliensis*), dolphinfish (*Coryphaena hippurus*), hake (*Merluccius gayi*) and chub mackerel (*Scomber japonicus*). Not much of a recovery in the ranking of catch volumes of jack mackerel is to be expected in 2017 due to the low catches of jack mackerel reported so far (updated to June 2017) and the observed increase in the catches of other species such as chub mackerel (*S. japonicus*) and bonito (*Sarda chiliensis*).

There are three types of fleets authorized to fish for jack mackerel in national waters: the industrial purse seine fleet (composed of 104 industrial purse seiners with a total hold capacity of 33,359 m^3); the small-scale fleet (around 100 small vessels with an average hold capacity of 12 m^3); and the artisanal fleet (around 500 boats with an average hold capacity of 8 m^3). The industrial purse seine fleet fishes for jack mackerel but also targets chub mackerel, bonito and other mid-size pelagics using similar searching strategies and the same 38 mm mesh-size purse-seines, but switches gear and adopts different search strategies to target anchoveta whenever this fishery is open. On the other hand, the small-scale and artisanal fleets are more flexible and opportunistic, and target indistinctly a large variety of species depending on their availability and market demand.

4.1 Catch trends

As in 2015, catches of jack mackerel in 2016 and 2017 continue to be low (Figure 8) and this appears to be closely associated with the impacts of the recent El Niño. In particular, it is worth noting the noticeable decline in the jack mackerel landings during the peak of the 2017 coastal El Niño in February and March 2017 (Figure 9). Abundance indices were also very low in 2015 and particularly in 2016 and 2017.

The annual jack mackerel catch per unit effort (CPUE) index expressed as the catch (in tonnes) per TRB-trip of the average industrial purse seine vessel during January-April of each year between 2010 and 2017 is plotted in Figure 10 side by side with the observed anomalies of the sea surface temperature (SSTA) measured at IMARPE's coastal station in Callao (at 12°S) in the same months. The yearly fluctuations of these observed CPUE and SSTA indices may help in illustrating the impact of environmental factors on the annual catches of jack mackerel off Peru by noting that the highest CPUE values occur in 2011, 2012 and 2014, when large but not extreme negative

SSTA values (between -0.3 and -1.5°C) were observed. While the lowest CPUEs occur with more extreme negative SSTA values (of -2.1°C) as in 2013, or with moderate to high positive SSTA values (between +0.2 and +1.8°C) as in 2010, 2015, 2016 and 2017 (Figure 10).

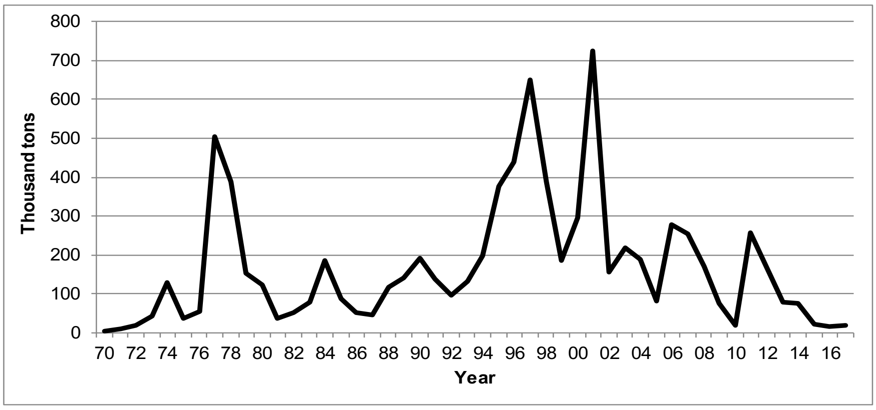


Figure 8.- Annual landings of jack mackerel *T. murphyi* in Peru, years 1970-2017 (updated to June 2017)

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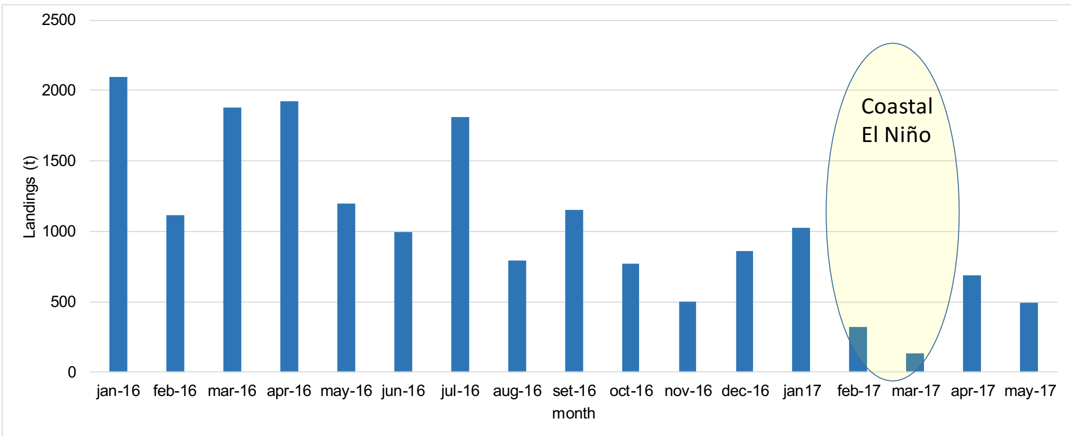

Figure 9.- Monthly landings of jack mackerel T. murphyi in Peru between January 2016 and May 2017

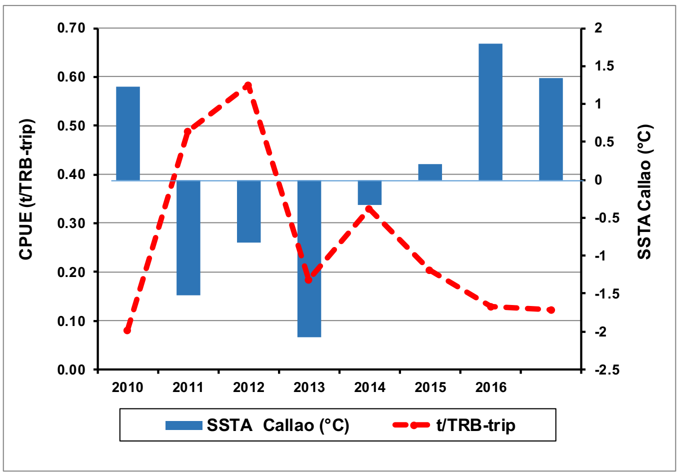

Figure 10.- Annual CPUE index of jack mackerel *T. murphyi* in tonnes per TRB-trip of an average industrial purse seine vessel (dashed red line) and Sea Surface Temperature Anomaly (SSTA) in Callao (solid blue bars) during January-April of each year between 2010 and 2016

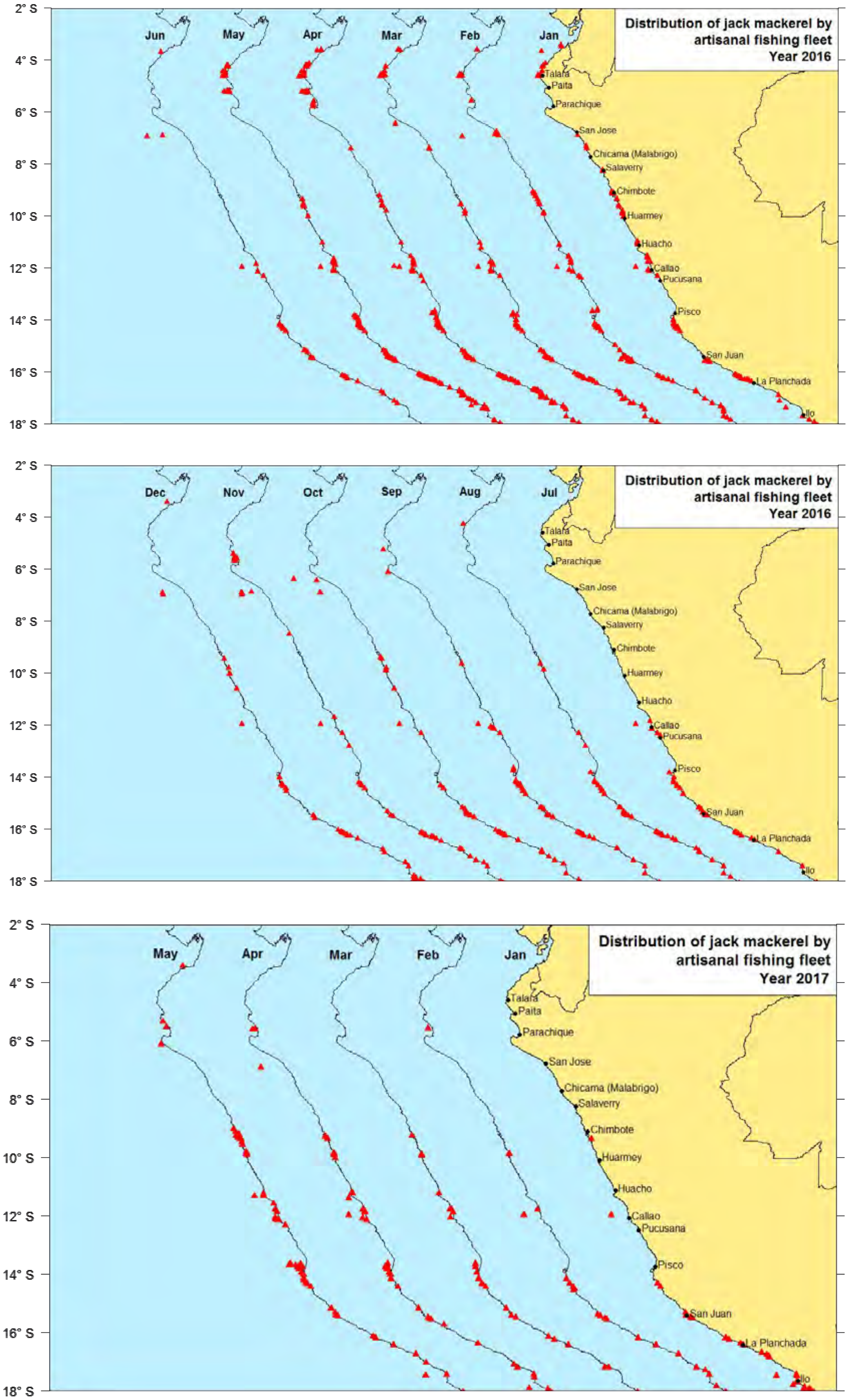

Figure 11.- Distribution of the jack mackerel (*Trachurus murphyi*) fishing areas in Peru, by month, from January 2016 to June 2017

The industrial purse seine fleet didn't target on and didn't report catches of jack mackerel during 2015, 2016 and 2017. This was mainly due to the scarcity of attractive enough concentrations of jack mackerel and the increased abundance and high availability of other species, in particular anchoveta and chub mackerel. So, all the catches of jack mackerel during 2015, 2016 and 2017 have been taken by the artisanal and the small-scale purse seine fleets.

Similarly to 2015, during 2016 and 2017 the fishing grounds for jack mackerel by the artisanal and small-scale purse seine fleets have had a very coastal geographical distribution (Figure 11). During January-December 2016 catches have been restricted to a narrow coastal band along the whole Peruvian coast, within 20 nm and in some cases only 10 nm from the coastline, mostly off Talara (04°35'S), Chancay (11°34'S) to Pucusana (12°25'S), Pisco (13°42'S), and Atico (16°14'S) to Ilo (17°39'S). During January-May 2017 the main fishing areas were also located very close to the coastline and due to the stronger impact of the coastal El Niño in the north, during January-March 2017 the jack mackerel fishing grounds were mostly restricted to the south of Callao (12°02'S) and to the south of Chimbote (09°04'S) during April and May 2017.

4.2 Size structure

Several modal groups of jack mackerel were observed in the fishery between January and October 2016 with younger individuals in summer and fall, and a predominance of adults with modal lengths between 32 and 38 cm total length in winter and spring (Figure 12). During 2017, the size frequency distributions during summer (January-March) were dominated by larger adult fish between 34 and 38 cm total length, while smaller size-groups between 22 and 30 cm total length were observed in May.

5. STOCK ASSESSMENT

This section provides a brief summary of the 2016 assessment of the Peruvian stock of jack mackerel (far-north stock) followed by a 2017 review and update.

5.1. 2016 assessment and 2017 TAC

In December 2016 IMARPE updated the available 2016 jack mackerel assessment in order to advise to the Vice-Ministry of Fisheries on the most current situation of the stock and the estimated Total Allowable Catch (TAC) for 2017. This assessment was based on the latest version of the JJM model developed during the 4th Meeting of the Scientific Committee held in The Hague, Kingdom of the Netherlands, in October 2016 (SPRFMO, 2016).

The stock size estimated in January 1st 2017 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. For each case, the fishing effort to be applied was estimated taking into account the risk that the biomass estimated at January 1st 2018 was lower than that estimated for 2017. For the estimation of TAC 2017, an F value equal to the average F of the last three years was considered. This resulted in an estimated TAC of 107 000 t and an F value of 0.045 with an estimated risk of 15.5% that the biomass projected to January 1st 2018 be lower than that estimated for 2017. On this it is noted that 2015 and 2016 may not the best years to be taken as a reference because this period was abnormal, heavily influenced by the effects of the recent strong 2015-16 El Niño causing lower jack mackerel concentrations and lower catches off Peru.

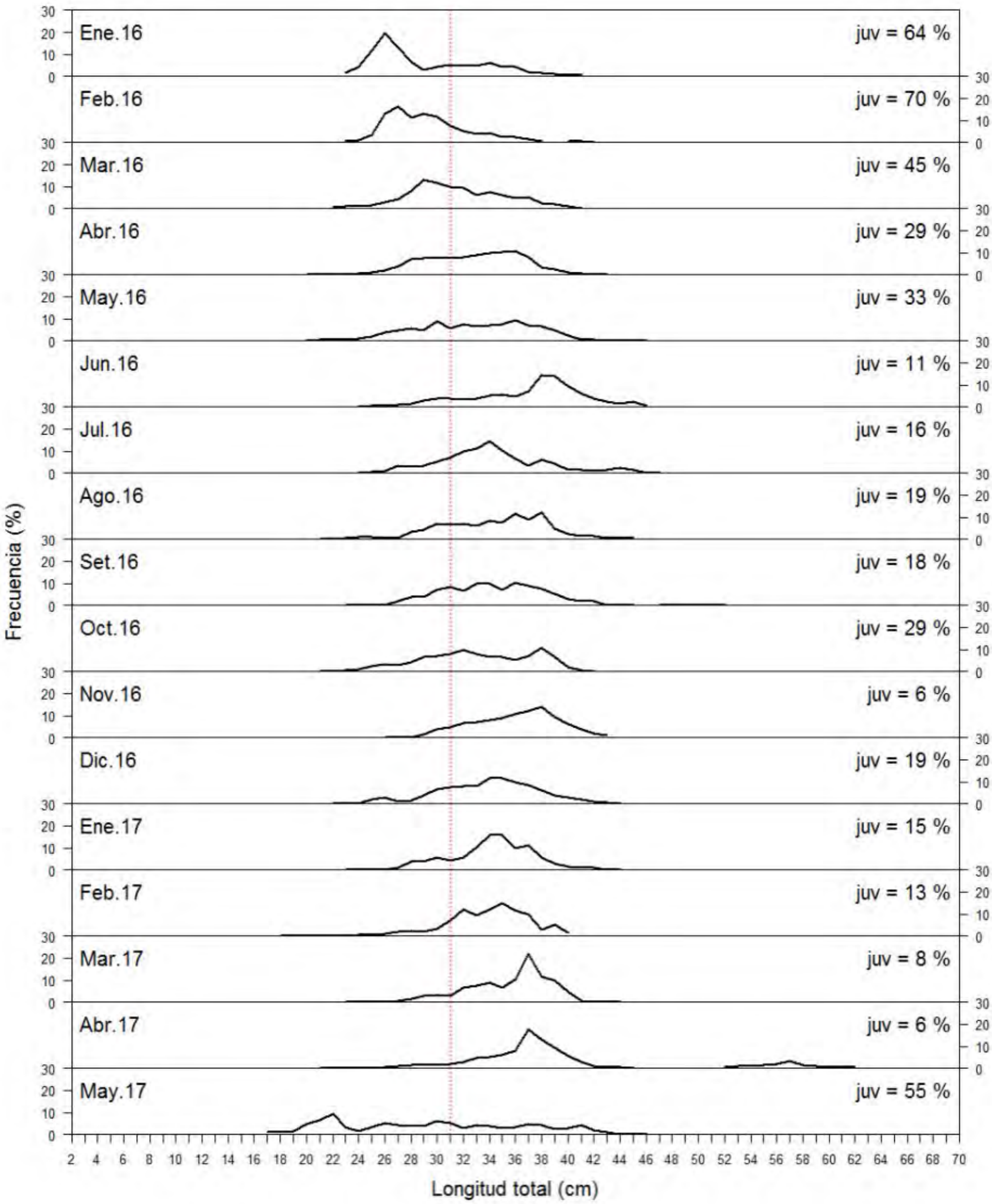

Figure 12.- Size frequency distribution of jack mackerel *Trachurus murphyi* caught in Peruvian jurisdictional waters by all fleets by month between January 2016 and May 2017

5.2. 2017 assessment

The main purpose of the 2017 assessment was to update the model with the most recent data and information up to June 2017, with the same configurations of the JJM of 2016. As noted below, this updated 2017 assessment produced very similar TAC estimates with higher risk, but with very similar F and biomass trends to those obtained in the 2016 assessment.

5.2.1 Updated information used in the 2017 assessment

Information about catch, catch at length, and catch at age was updated to 2017. 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 CPUE index uses all the trips based on the observation that when the anchoveta fishing season is closed the industrial fleet aims indistinctly at catching jack mackerel *T. murphyi* and/or mackerel *S. japonicus* (and/or sardine *Sardinops sagax* and other mid-size pelagics if/when available) with no real preference for one or the other. GAM models were used for the standardization of CPUE, where time (year, month), space (latitude, offshore distance) and size of vessels (represented by the hold capacity) were used as explanatory variables.

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 early in 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 60mn) where there is a reduced probability of finding the best concentrations of jack mackerel.

Table 1.- Data used in the 2017 assessment

Type	Data	Details
From the fishery	Catch	1970 – 2017
	Catch-at-length	1980 – 2017
	Catch-at-age	1980 – 2017
	CPUE	2002 – 2014
	Selectivity	Dome shaped
Fishery independent	Echo-abundance	1985 – 2014
	Selectivity	Logistic
Biological	Growth parameters	$k=0.165\ y^{-1}$, $L_\infty=80.4$cm
	Natural mortality	M=0.33
	Maturity at age	First mat=2 y
	Weight at age	From updated W-L parameters

Regarding to biological data, sexual maturity at age was estimated from a length based ogive using the information described in 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. More details are given in Table 1.

5.2.2 Joint Jack Mackerel model (JJM)

The same configurations of the 2016 assessment were implemented in the 2017 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 the Table 2.

Table 2.- Model configurations implemented in the 2016 JJM assessment

Model	Description
Data update	
0.0	- As 2016 configuration and data - Indices: *echo-abundance* (cv=0.2) and CPUE (cv=0.2) - Stock-recruitment relationship: recruits from 1970 to 2012 to scale, with two regimes
0.1	As in model 0.0 but with updated catch and length composition to 2017
Model configuration	
1.0	As in model 0.1
1.1	As in model 1.0 but steepness = 0.6
1.2	As in model 1.0 but steepness = 0.8

The addition of updated information, either age compositions or catches (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, the first one with very high biomass during the 1980s and 1990s, and the second one with lower biomass since 2000 (Figure 13a). Similarly, the mean value of fishing mortality estimated for years between 1970 and 2016 was very similar for the two configurations, as well as their distributions (Figure 13b).

The group 1 models were used to analyze the sensibility of the recruitment parameters, through the *steepness*. The trends in biomass (Figure 13c) were very similar in the various configurations, while configuration 1.2 was the one that produced lower values of biomass and therefore the highest values of fishing mortality (Figure 13d).

The outputs of the final configuration shows that the general trends in this 2017 assessment are very similar to those in the 2016 assessment. 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 14 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

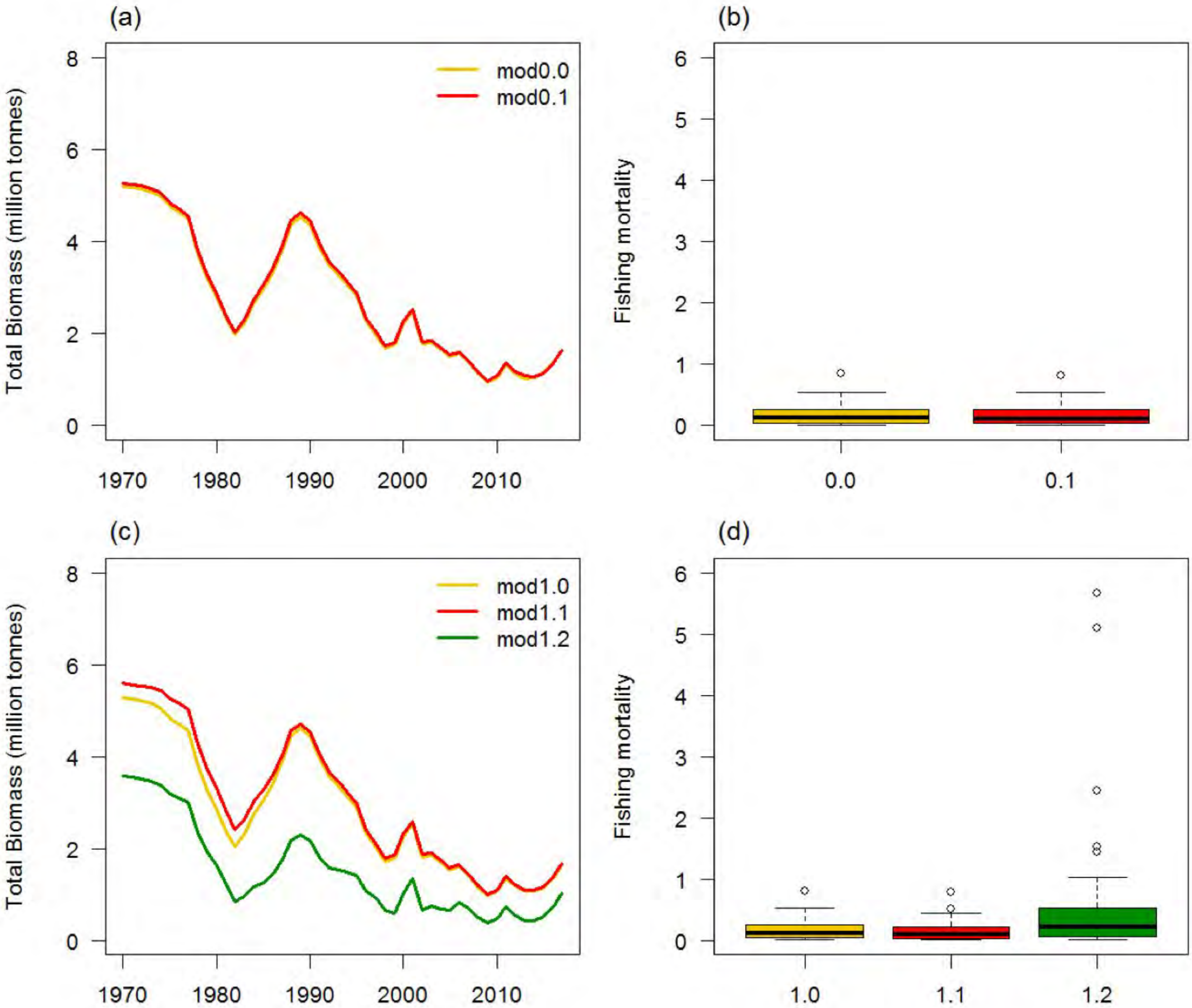

Figure 13.- Total biomass series and yearly fishing mortality distribution estimated for group 0 models (panels a & b, testing the sensitivity to updated data); and, group 1 models (panels c & d, testing the sensitivity to assumptions on recruitment productivity

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 14, lower panel). With one high productivity regime from 1970 to 1996 and a lower productivity regime from 2001 to 2012. The period 1997-2000 was not taken into account due to the high variability observed for those years, mainly induced by the 1997-1988 El Niño and probable instability caused by the regime change itself.

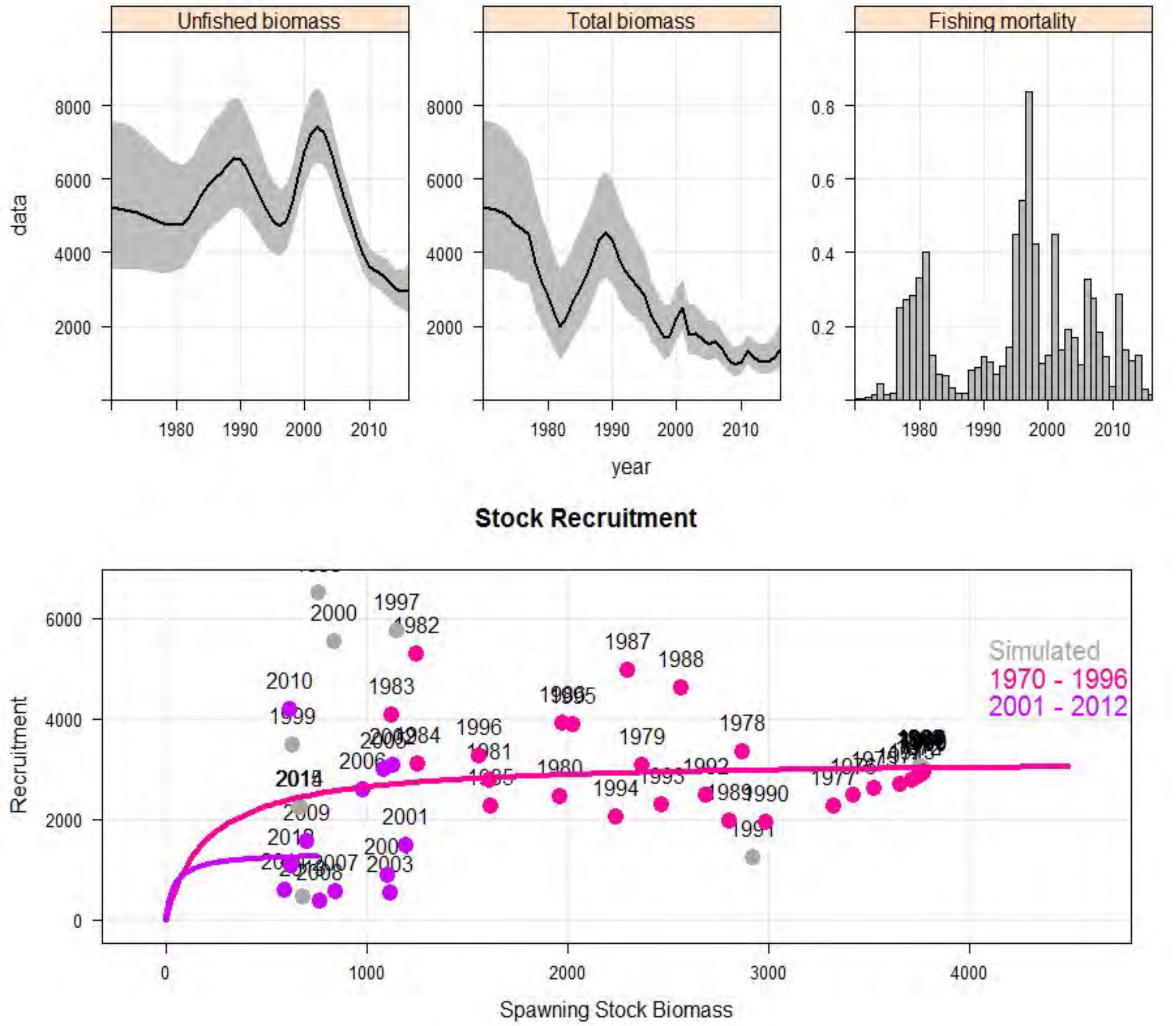

Figure 14.- Outputs of the final configuration of the JJM showing the history and current situation of the Peruvian (far-north) stock of jack mackerel *Trachurus murphyi*. Unfished biomass, total biomass and fishing mortality are presented at the top panels. The stock-recruitment relationship showing two regimes is presented in the lower panel

6. BIBLIOGRAPHIC REFERENCES

Alegre, A., Espinoza, P., Espino, M., 2013. Ecología trófica del jurel *Trachurus murphyi* en el Perú entre 1977 – 2011. Revista Peruana de Biología 20, 75–82.

Alegre, A., Bertrand A., Espino M., Espinoza P., Dioses T., Ñiquen M., Navarro I., Simier M., Ménard F. 2015. Diet diversity of jack and chub mackerels and ecosystem changes in the northern Humboldt Current system: A long-term study. Progress in Oceanography 137: 299–313.

Csirke, J., R. Guevara-Carrasco & M. Espino (eds). 2013. Ecology, fishery and conservation of Jack mackerel (*Trachurus murphyi*) in Peru. Rev. peru. biol., special issue (published in Spanish with titles, abstracts and captions in English), 20 (1): 001-114

Gutiérrez, M., Ramírez, A., Bertrand, S., Morón, O., Bertrand, A., 2008. Ecological niches and areas of overlap of the squat lobster 'munida' (*Pleuroncodes monodon*) and anchoveta (*Engraulis ringens*) off Peru. Progress in Oceanography 79, 256-263.

IMARPE-PRODUCE. 2012. National report on the situation of the Peruvian stock of Jack mackerel (northern stock) and the Peruvian fishery in national jurisdictional waters. Peru 2nd National Report 2012. 11th Meeting of the Science Working Group of the SPRFMO, Lima, Peru, 15-19 October 2012. Doc. SPRFMO SWG-11-08a: 65p.

IMARPE-PRODUCE, 2012a. Characteristics of the Peruvian stock (northern stock) of Jack mackerel (*Trachurus murphyi*) in the Southeast Pacific and notes on the scientific basis for its differentiation. 11th Meeting of the Science Working Group of the SPRFMO, Lima, Peru, 15-19 October 2012. Doc. SPRFMO SWG-11-JM-03: 27p

IMARPE-PRODUCE. 2013. National report on the situation of the Peruvian stock of Jack mackerel (far-north stock) and the Peruvian fishery in national jurisdictional waters. Peru National Report No 2. 1st Meeting of the SPRFMO Scientific Committee, La Jolla, Ca., U.S.A., 21-27 October 2013. Doc. SPRFMO SC-01-13: 31p

IMARPE-PRODUCE. 2014. National report on the situation of the Peruvian stock of Jack mackerel (far-north stock) and the Peruvian fishery in national jurisdictional waters. Peru National Report No 2. 2nd Meeting of the SPRFMO Scientific Committee, Honolulu, Hawaii, U.S.A., 01-07 October 2014. Doc. SPRFMO SC-02-17: 40p

IMARPE-PRODUCE. 2015. National report on the situation of the Peruvian stock of Jack mackerel (far-north stock) and the Peruvian fishery in national jurisdictional waters. Peru National Report No 2. 3rd Meeting of the SPRFMO Scientific Committee, Port Vila, Vanuatu, U.S.A., 28 September - 03 October 2015. Doc. SPRFMO SC-03-19: 21p

IMARPE-PRODUCE. 2016. National report on the situation of the Peruvian stock of Jack mackerel (far-north stock) and the Peruvian fishery in national jurisdictional waters. Peru National Report No 2. 4th Meeting of the SPRFMO Scientific Committee, The Hague, Netherlands, 10-15 October 2016. Doc. SPRFMO SC-04-09: 23p

Konchina, Y., 1981. The Peruvian jack mackerel, *Trachurus symmetricus murphyi*, a facultative predator in the coastal upwelling ecosystem. Journal of Ichthyology 21, 46–59.

Muck, P. & Sánchez, G., 1987. The importance of mackerel and horse mackerel predation for the Peruvian anchoveta stock (a population and feeding model). In: Pauly, D. Tsukayama I. (Eds.). The Peruvian Anchoveta and Its Upwelling Ecosystem: Three Decades of Change. ICLARM Studies and Reviews (15), pp. 276-293.

Dioses, T. 1995. Análisis de la distribución y abundancia de los recursos jurel y caballa frente a la costa peruana. Informe Progresivo del Instituto del Mar del Perú (IMARPE), Callao, Perú, N° 3: 55 pp

Dioses, T. 2013. Age and growt.h of Jack mackerel *Trachurus murphyi* in Peru. In: J. Csirke, R. Guevara-Carrasco & M. Espino (eds). 2013. Ecology, Fishery and Conservation of Jack mackerel (*Trachurus murphyi*) in Peru. Rev. peru. biol. special issue (published in Spanish with titles, abstracts and captions in English), 20 (1): 045-052.

Dioses, T. 2013a. Abundance and distribution patterns of Jack mackerel *Trachurus murphyi* in Peru. In: J. Csirke, R. Guevara-Carrasco & M. Espino (eds). 2013. Ecology, Fishery and Conservation of Jack mackerel (*Trachurus murphyi*) in Peru. Rev. peru. biol. special issue (published in Spanish with titles, abstracts and captions in English), 20 (1): 067-074.

Perea, A., J. Mori, B. Buitron & J. Sánchez. 2013. Reproductive aspects of Jack mackerel *Trachurus murphyi*. In: J. Csirke, R. Guevara-Carrasco & M. Espino (eds). 2013. Ecology, Fishery and Conservation of Jack mackerel (*Trachurus murphyi*) in Peru. Rev. peru. biol. special issue (published in Spanish with titles, abstracts and captions in English), 20 (1): 020-034.

SPRFMO, 2016. Report of the 4th Scientific Committee Meeting, The Hague, Kingdom of the Netherlands, 10-14 October 2016. SPRFMO Scientific Committee SC-04 report: 103p.