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Peru's Annual Report Part II: National Jurisdictional Waters

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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

2016

SUMMARY

This report updates information on the biology and fishery of jack mackerel (*Trachurus murphyi*) in Peru presented in previous SPRFMO Scientific Committee meetings. During 2014, 2015 and the first part of 2016 the Peruvian coastal areas have been affected by warmer than normal conditions typical of a weak El Niño during 2014 and a strong El Niño during 2015 and early 2016. Environmental conditions entered into a cooling trend while still remaining warmer than normal only towards the end of the first semester of 2016. 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 disappear and moved closer to the coast, disrupting was 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 and the first part of 2016. During 2014 and predominantly during 2015 and early 2016 jack mackerel concentrations were mostly found in coastal areas, within 20 nm and some times limited to the 10 nm from the coast, within reach of the artisanal and small scale fleet but outside the usual fishing grounds of the industrial purse seine fleet. The catch of jack mackerel drop from a total of 74,528 t in 2014 to only 22,158 t in 2015 (almost all caught by the small-scale and artisanal fleets) and so far only the small-scale and artisanal fleets have captured jack mackerel this year, reporting an estimated 9,209 t from January to June 2016. Various options for the 2016 TAC were considered during a December 2015 assessment based on the latest version of JJM model developed during the 3th Meeting of the Scientific Committee and the final decision was to accept a risk of 3.9% with an F_{2016} = 0.0325 and an estimated TAC of 93 000 t for 2016. The *status-quo* (2015 conditions) option estimated a much lower TAC with slightly lower estimated risk and F but this option was not selected based on the observation that 2015 was an abnormal year, heavily influenced by the strong effects of the most recent El Niño. A more recent 2016 assessment was made using the JJM with information updated to June 2016, and considering new estimated risks and F levels the resulting TACs were very similar to those estimated in the December 2015 assessment.

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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) and in IMARPE's recent publication on the biology and fishery of the jack mackerel (*Trachurus murphyi*) in Peru (Csirke et al. 2013).

Warmer than normal environmental conditions compatible with a weak to moderate El Niño prevailed off Peru during part of 2014 while the area was affected by a stronger El Niño during 2015 and the earlier part of 2016. As explained below, these warmer than normal environmental conditions contributed to the low observed abundance indexes and low catches of jack mackerel in Peruvian jurisdictional waters in 2014 and particularly in 2015 and the first part of 2016.

2 THE MARINE ENVIRONMENT

A weak El Niño developed during 2014 and after a short period of closer to normal environmental conditions a moderate to strong El Niño developed during the first part of 2015, to develop into a clearly strong El Niño during the second part of 2015 and early 2016. Environmental conditions entered into a cooling trend while still remaining warmer than normal typical of El Niño towards the end of the first semester of 2016. This is well described by the monthly thermal anomalies (°C) based on the Coastal Index of El Niño (ICEN) in the El Niño 1+2 region shown in Figure 1.

This El Niño Coastal Index categorizes short-term environmental conditions such as El Niño (EN) and La Niña (LN) and is calculated as the three-month moving average of the anomalies of sea surface temperature in the El Niño 1+2

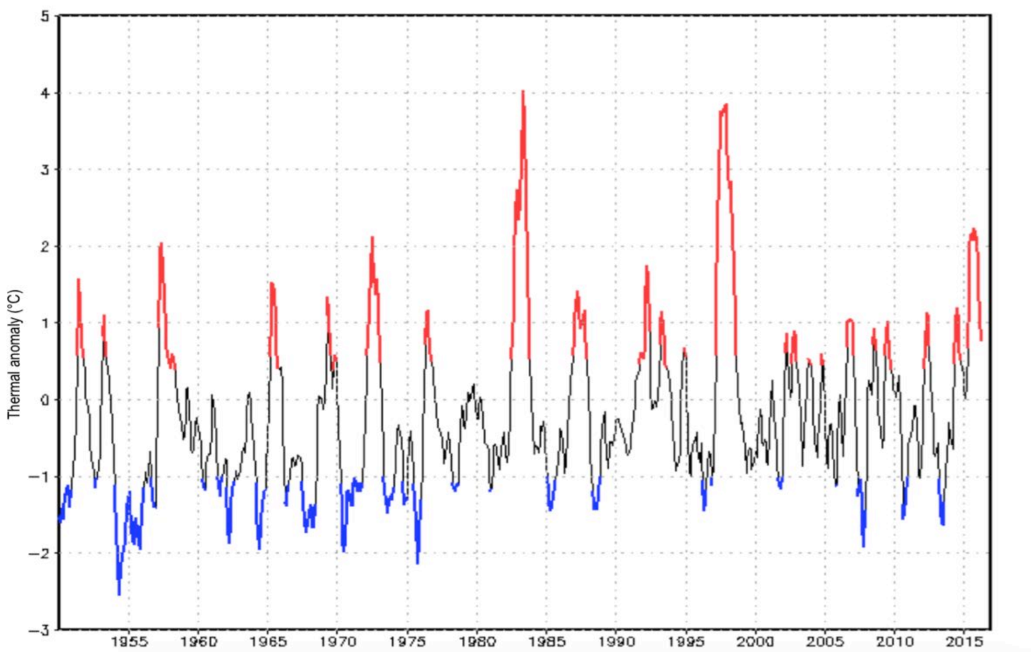

Figure 1.- Monthly thermic anomalies (°C) based on the Coastal Index of El Niño (ICEN) in the El Niño 1+2 region off Peru, three-month moving average between January 1950 and June 2016. The anomalies are referred to a 30-year (1981-2010) monthly mean pattern. El Niño (EN) conditions are highlighted in red and La Niña (LN) conditions arte highlighted in blue

region (between 00-10°S and 90°-80°W) taking as reference the monthly mean sea surface temperature pattern of 1981-2010. In this particular case, in addition to showing the evolution of the weak 2014 El Niño followed by a strong 2015-16 El Niño, Figure 1 also shows the development of earlier El Niños and La Niñas and it is worth noting that the 2015-16 El Niño appears as the third stronger El Niño since 1950, third only to the very strong 1982-83 and 1997-98 El Niño and slightly stronger than the 1972-73 El Niño.

While the El Niño Coastal Index describes the environmental conditions in the Southeastern Eastern Pacific between 00-10°S and 90°-80°W (El Niño region 1+2), IMARPE also uses a similar more coastal index based on its own sea surface temperature (SST) records from its network of coastal stations. The resulting indexes of sea surface temperature anomalies (SSTA) along the Peruvian coast from 1976 to 2016 are plotted in Figure 2, showing the changes in the coastal sea surface temperatures and the development of El Niño and La Niña conditions along the whole Peruvian coast.

As can be noted in Figure 2, the 2014 El Niño is confirmed as a weak El Niño while the 2015-16 El Niño is confirmed as a strong one, following in strength the latest two very strong El Niños of 1982-83 and 1997-98. These two El Niños had a stronger and longer lasting effect along the whole Peruvian coast, while the 2015-16 El Niño didn't last as long and had a stronger effect to the north of Callao (12°S) even if it did affect the whole Peruvian coast.

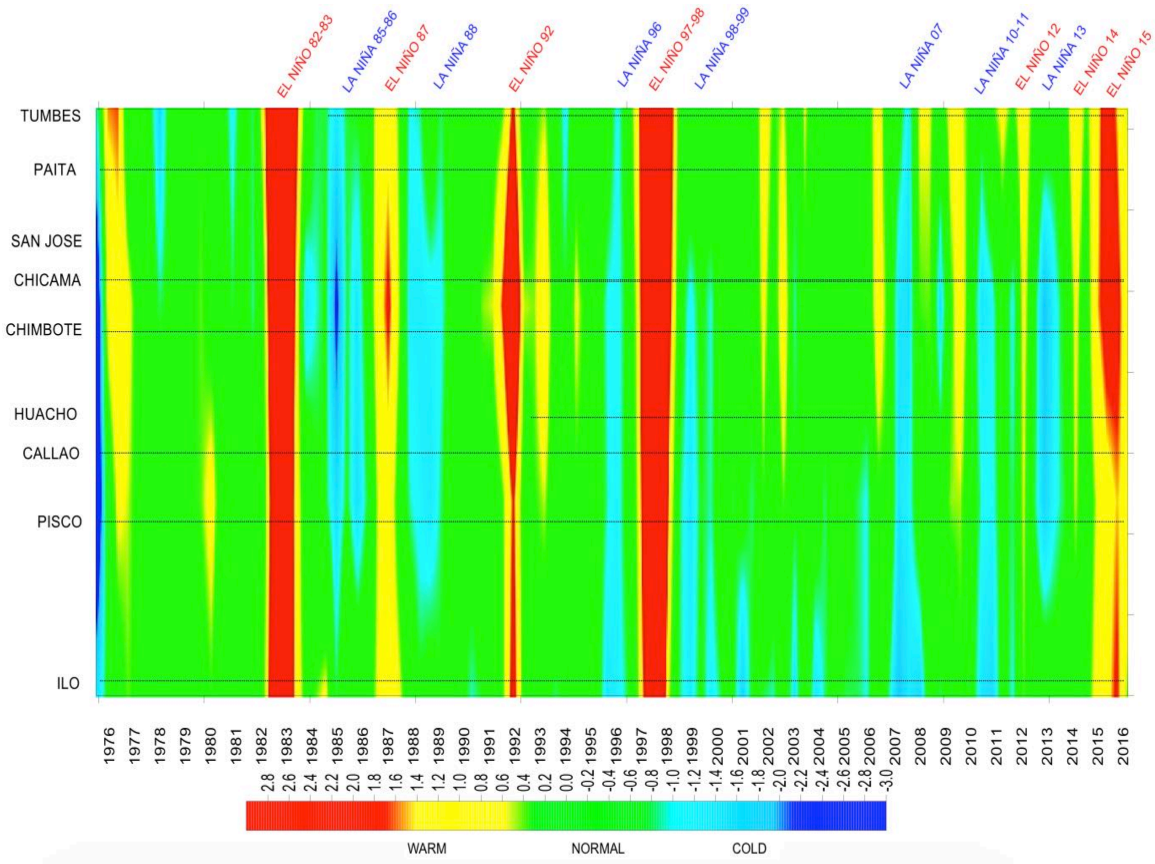

Figure 2.- Sea Surface Temperature Anomalies (SSTA, in °C) from IMARPE´s coastal stations, by latitude along the entire Peruvian coast, years 1976–2016 (until June 2016)

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 2015).

3.1 Spatial distribution

Santander and Flores (1983) and Dioses (1995, 2013a) describe the preferred habitat of jack mackerel off Peru as that represented by the oceanic front of mixed waters formed by the encounter of warmer Subtropical Surface Waters and Colder Coastal Waters, noting that the observed changes in this oceanic front tend to explain well most of the changes in the abundance and in the inshore-offshore and vertical distribution of the main jack mackerel concentrations off Peru. They also noted that jack mackerel off Peru seems to be adapted to waters masses slightly warmer (above 15°C) than further south and explain that off Peru the depth of the 15°C isotherm is usually associated to the oxygen isocline of 1 mL/L, which is the minimum content of oxygen limiting the vertical distribution of the jack mackerel shoals. Off Peru, closer to the coast the water columns with oxygen content equal or higher than 1 mL/L usually reach depths of 20-30 m, while at 90 nm from the coast the water masses with these characteristics can reach depths of 80-100 m. It has been observed that in Peru it is within these water masses and distance from the coast where the best fishing grounds for the purse seiners fishing for jack mackerel usually occur.

I line with the above observations the warmer El Niño conditions in 2014, 2015 and early 2016 have caused a displacement of the jack mackerel concentrations. During 2014 and particularly during 2015 and early 2016 jack mackerel concentrations were only found in coastal areas, within 20 nm and some times limited to the 10 nm from the coast, within reach of the artisanal and small scale fleet (Figures 7 and 8) but outside the usual fishing grounds of the industrial purse seine fleet. This change in the spatial distribution of jack mackerel in 2014 and particularly 2015 and early 2016 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.

3.2 Age and growth

The few age readings and length frequency distributions observed during 2014, 2015 and early 2016 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.

Also it is worth reporting that as part of Peru's contribution to the activities of the Task Team of the SPRFMO Scientific Committee on jack mackerel ageing and growth, IMARPE staff has conducted a preliminary analysis of the growth microstructures of jack mackerel otoliths from Chile and Peru. Two known criteria were applied in this analysis, the Individual Mark Reading (IMR) and the Group Band Reading (GBR), and as described in a separate report (Goicochea and Dioses 2016) the results of the IMR analysis confirm earlier ageing results reported by Goicochea (2013) about the fast growth of jack mackerel in Peru (…and probably also in northern Chile?). What is somehow surprising is that when the GBR criteria is applied the estimated growth and ageing suggest a much faster growth than previously estimated. In fact, when the GBR criteria is applied the estimated ageing suggest that at the age of 365 days jack mackerel reaches a total length of 29 cm (27 cm FL), when according to the traditional readings currently in use jack mackerel should reach this length only when two-years old. There is no doubt that the relevance of this observation calls for a more in-depth analysis of the jack mackerel ageing processes and reference should be made to the report by Goicochea and Dioses (2016) for further details on this issue.

3.3 Reproductive aspects

A recent update of the Perea *et al* (2013) long-term analysis of the reproductive process of the Peruvian jack mackerel based on the monthly variability of the gonadosomatic index shows that the intensity of the reproduction process continues to be low (Figure 3), with the latest 2015-2016 reproductive pulse below the 2002-2012 mean values taken as standard.

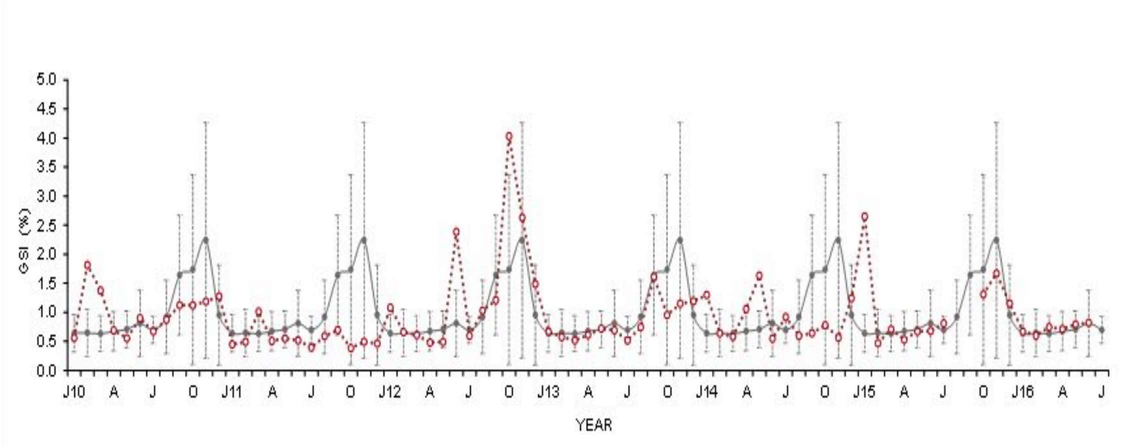

Figure 3.- Monthly variability of the Gonadosomatic Index of Jack mackerel in Peruvian jurisdictional waters, 2010-2016. The grey dots and vertical lines are the monthly means and their respective standard deviations for the years 2002-2012 taken as the standard. The red circles are the actual observed monthly values from January 2010 to June 2016

3.4 Trophic relationships

The updated information on jack mackerel's diet composition based on the work by Alegre et al. (2013, 2015) confirms the great diversity of preys in the diet of jack mackerel, with a clear predominance of Euphausiidae. The stronger dominance of Euphausiidae in the diet of jack mackerel during the warmer period of 1977-2000 and the more diversified diet during the slightly colder period starting in 2001 has already been noted (Alegre et al. 2013, 2015; IMARPE-PRODUCE 2015).

As shown in Figure 4, Euphausiidae were strongly dominant in jack mackerel's diet before 2000, while after 2000 *Pleuroncodes monodon* and zoea larvae took much more importance. The increase of *P. monodon* in the diet is consistent with the dramatic increase in *P. monodon* observed off Peru since the late 1990s (Gutiérrez et al. 2008). Similarly, the population of coastal sand crab *Emerita analoga*, that makes the bulk of zoea larvae (Blaskovic et al. 2009) was likely favoured by the increase in productivity observed off Peru during the last

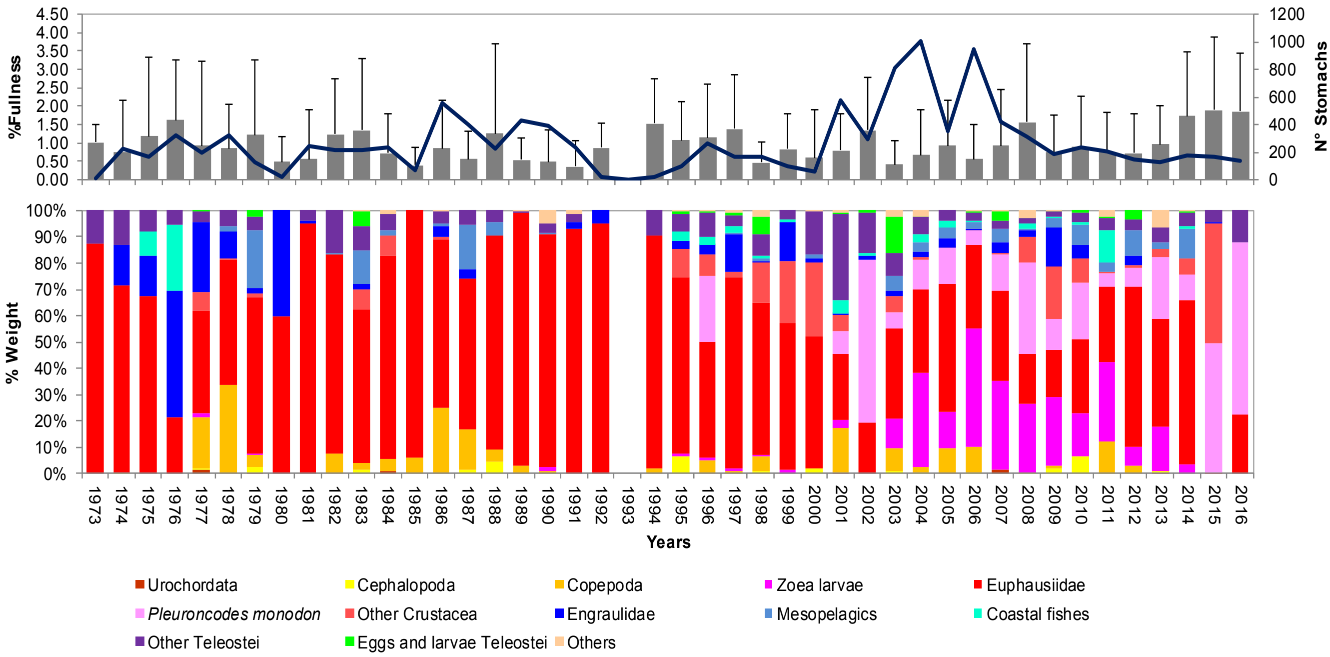

Figure 4.- Index of fullness (in %, vertical bars, top panel), sample size (solid lines, top panel) and proportion of preys (vertical bars, lower panel) in stomach content of jack mackerel *Trachurus murphyi* off Peru from 1973 to 2016 (last year updated to June 2016 only)

two decades (Sifeddine et al. 2008; Gutiérrez et al. 2009). The case for Euphausiidae is more paradoxical. Indeed Euphausiidae contribution to jack mackerel diet appears to be very high until the year 2000 and dropped thereafter. This trend shift is contradictory with the actual trend in Euphausiidae abundance off Peru reported by Ayón et al. (2011), who observed lower biomasses of Euphausiidae from the late 1970 throughout the 1980s, when the Northern Humboldt Current system was reported to be less productive and more oxygenated. It is also worth noting that in 2014 there was a noticeable increase in the diet contribution of Euphausiidae with a drop in the intake of *P. monodon* and zoea larvae (Figure 4). However, this was short lasting as the diet contribution of *P. monodon* and zoea larvae increased again in 2015 and the first part of 2016.

4 DESCRIPTION OF THE FISHERY

For more than a decade until 2014 catches of jack mackerel (*T. murphyi*) ranked third in importance by volume at national level, after anchoveta (*Engraulis ringens*) and jumbo squid (*Dosidicus gigas*) (Ñiquen et al. 2013, IMARPE-PRODUCE 2015). However, due to lower catches of jack mackerel and the increase in catches of other species in 2015 jack mackerel fall to the seventh position, being preceded (in order of importance by catch volumes) by: anchoveta (*E. ringens*), jumbo squid (*D. gigas*), bonito (*Sarda chiliensis*), dolphinfish (*Coryphaena hippurus*), hake (*Merluccius gayi*) and mackerel (*S. japonicus*). Not much of a recovery of jack mackerel in the 2016 ranking of catch volumes is to be expected due to the low catches of jack mackerel reported so far (updated to June 2016) and the increase bein observed in the catches of other species such as 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 33,359m^3); the small-scale fleet (around 100 small vessels with and 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 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

Annual catches of jack mackerel in Peruvian jurisdictional waters have been highly variable with pulses of high and low catches throughout the years. The highest catch pulses peaked in 1977, 1997 and 2001, with a clear decreasing trend in recent years (Figure 5).

In 2014 the total catch of jack mackerel in Peruvian waters was 74,528 t, caught by all three fleets, industrial, small-scale and artisanal. However, in 2015 the total catch of jack mackerel drop to only 22,158 t, almost all caught by the small-scale and artisanal fleets. The industrial fleet made no significant catches of jack mackerel in 2015, and so far (until June 2016) the only catches this year are those made by the artisanal and small-scale fleets that until June have reported an estimated total catch of 9,209 of jack mackerel.

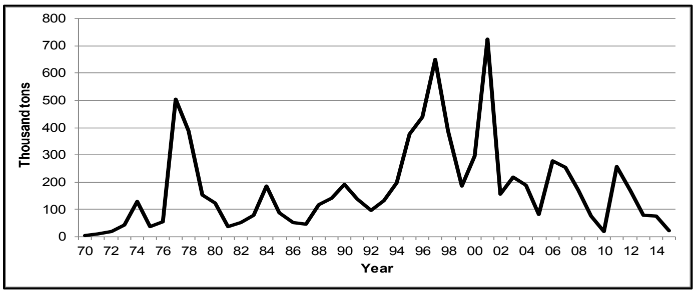

Figure 5.- Annual landings of jack mackerel *T. murphyi* in Peru, years 1970-2015

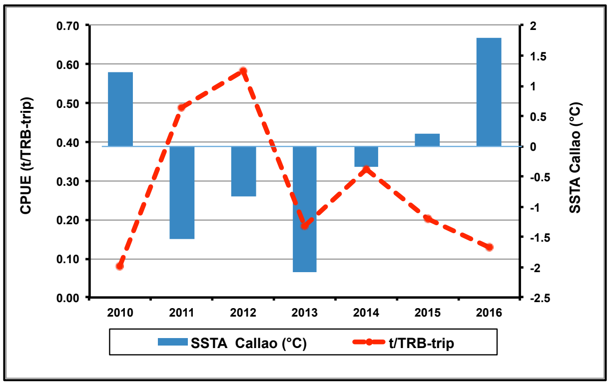

Figure 6.- CPUE index of jack mackerel (*T. murphyi*) in tonnes per TRB-trip of an average industrial purse seine vessel (dashed red line) and Sea Surface Temperature Anomaly (SSTA) in Callao (solid blue bars) during January-April, years 2010 to 2016

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 2016 is plotted in Figure 6 side by side with the sea surface temperature anomalies (SSTA) measured at IMARPE's coastal station in Callao (at 12°S) in the same months. The observed CPUE and SSTA fluctuations may contribute to illustrate the impact of environmental factors on the annual catches of jack mackerel off Peru. Since, as can be noted in Figure 6, 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 and 2016.

The geographical distribution of the jack mackerel catches by the artisanal and small-scale purse seine fleets during January-December 2015 (Figure 7) has been restricted to a narrow 10 to 20 nm coastal band along the whole Peruvian coast, with main fishing areas 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).

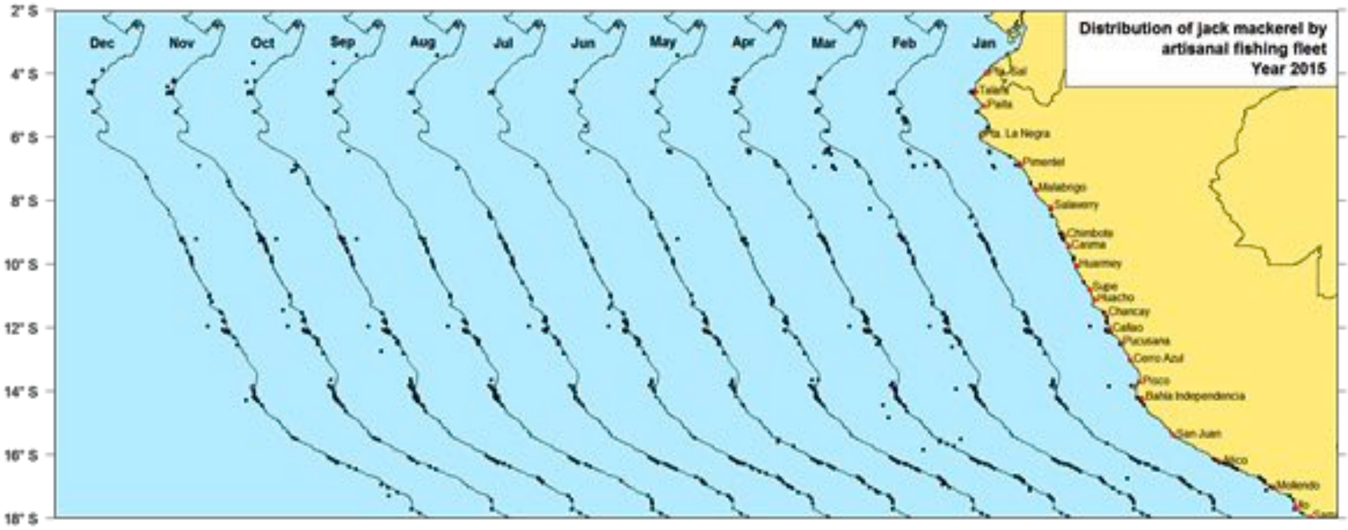

Figure 7.- Distribution of jack mackerel fishing areas in Peru during January-December 2015

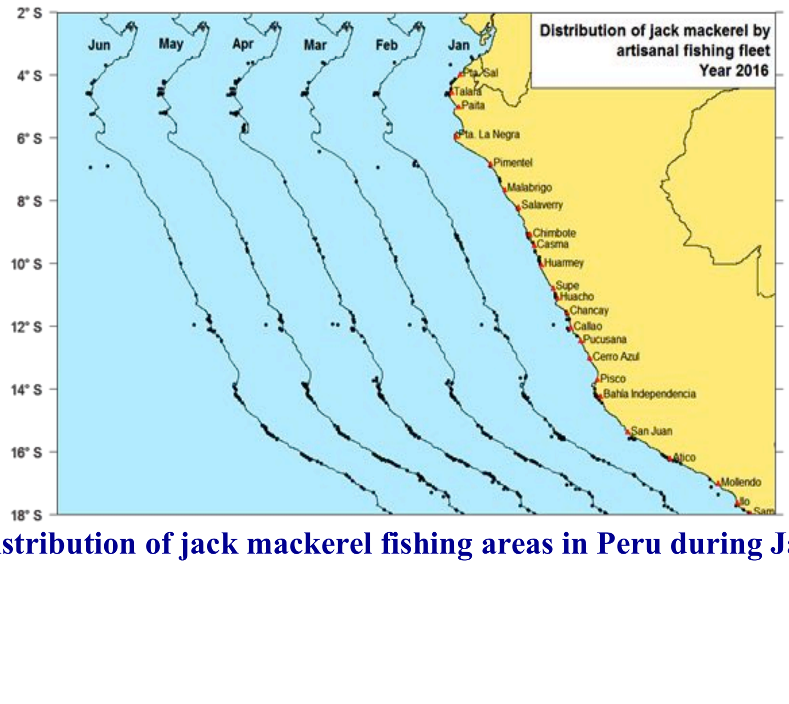

Figure 8.- Distribution of jack mackerel fishing areas in Peru during January-June 2016

Also only the artisanal and small-scale fleets fished for jack mackerel during the first semester of 2016 and their fishing grounds were also very close to the coast (Figure 8), with major fishing areas between Talara (04°35'S) and Paita (05°04'S) and south of Chancay (11°34'S) - mainly off Callao (12°02'S), Pisco (13°42'S), San Juan (15°21'S) and Atico (16°14'S).

4.2 Size structure

Several modal groups of jack mackerel were observed in the fishery between January and October 2015 with younger individuals in the autumn (April and

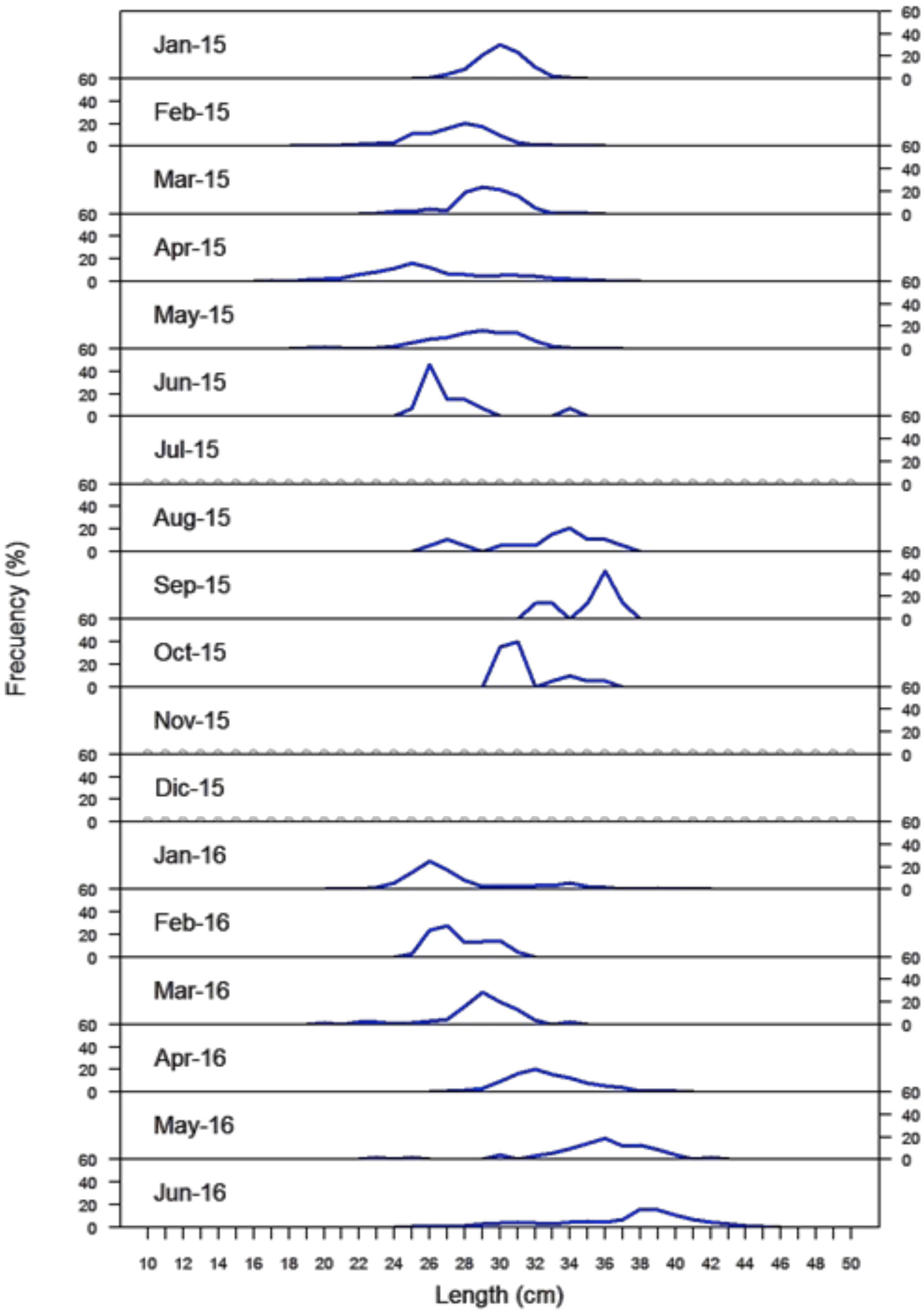

Figure 9.- Size frequency distribution of jack mackerel (*T. murphyi*) caught in Peruvian jurisdictional waters by all fleets by month between January 2015 and June 2016

May) and a predominance of adults with modal lengths between 31 and 34 cm total length in winter (August and September) (Figure 9). During 2016 smaller size-groups between 26 and 30 cm total length dominate in summer (January-March) with larger adult fish between 36 and 40 cm TL in May and June.

5 STOCK ASSESSMENT

This section provides a brief summary of the 2015 assessment of the Peruvian stock of jack mackerel (far-north stock) followed by a 2016 review and update.

5.1 2015 assessment and 2016 TAC

In December 2015 IMARPE updated the available 2015 jack mackerel assessment in order to advice to the Vice-Ministry of Fisheries on the most current situation of the stock and the estimated Total Allowable Catch (TAC) for 2016. This assessment was based on the latest version of the JJM model developed during the 3th Meeting of the Scientific Committee held in Port Vila, Vanuatu, in September-October 2015 (SPRFMO, 2015).

The stock size estimated at January 1st 2016 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 2017 was lower than that estimated for 2016. While the results indicate that the *status-quo* (2015 conditions) could be achieved with an estimated risk of 2.6% that the biomass projected to January 1st 2017 be lower than that estimated for 2016, and an $F_{status\text{-}quo}$ = 0.0165 and a TAC of 49 000 t, the final decision was to accept a 50% higher risk (of 3.9%) with an F_{2016} = 0.0325 and an estimated TAC of 93 000 t. On this it is noted that 2015 may not the best year to be taken as a reference for the *status-quo* because 2015 was an abnormal year, heavily influenced by the effects of the recent strong 2015-16 El Niño causing lower jack mackerel concentrations and lower catches off Peru.

5.2 2016 assessment

The main purpose of the 2016 assessment was to update the model with the most recent data and information up to June 2016 while testing different configurations of the JJM model applicable to this stock. Different configurations were used to test the sensitiveness to changes in the timing of the regime shift, stock abundance indexes and recruitment steepness. As noted below, this updated 2016 assessment produced very similar TAC estimates with higher risk and F values, but with very similar F and biomass trends to those obtained in the 2015 assessment.

5.2.1 Updated information used in the 2016 assessment

Information about catch, catch at length and catch at age was updated to 2016. In addition, a new index of CPUE was estimated (from the industrial fleet) and was updated to 2014. 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 information or data to be added.

The IMARPE´s Fisheries Monitoring System routinely collects catch and length compositions data. Year length-frequency distributions were converted to ages using the age and growth parameters estimated by Dioses (2013). A change was introduced with respect to the CPUE index used in the past. The previous CPUE index was estimated by selecting only those vessel-trips where jack mackerel represented 50% or more of the total catch assuming that this would better represent those trips specifically directed to jack mackerel. The new 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. However, this situation may change if mackerel continues to be found in relatively abundant high concentrations closer to the coast as has been observed during the last two years, since this may serve to discourage any attempt to search for jack mackerel in lower densities farther offshore and farther from port. The new CPUE was standardized using GAM models where time (year, month), space (latitude, offshore distance) and size of vessels (represented by the hold capacity) were used as explanatory variables.

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 was preferred to the acoustic biomass estimates used in the past 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).

It is known that the acoustic surveys conducted periodically by IMARPE follow a sampling design that is directed primarily to obtain acoustic biomass estimates of the anchoveta population, the most abundant and most important fish stock in Peruvian waters. This makes that the procedures and sampling grids of the acoustic surveys be adapted to the distribution and behavior of the anchoveta, which is usually found closer to the coast. Therefore, these acoustic surveys cover the coastal areas to maximum distances of 50 to 100 nautical miles from the coastline, even if it is known that the best concentrations of jack mackerel can be found farther away. Also, there are behavioral aspects typical of jack mackerel, such as the high vessel avoidance (particularly noticeable when shoals are closer to the surface) and the high avoidance (particularly by medium to large fishes) to the sampling-fishing gear used by the research vessel. It has been noted that due to the above the biological sampling being used provides at best a poor representation of the size-frequency distribution of the jack mackerel being observed by the echo sounder. In short, the echo-abundance values represented by the S_A index for jack mackerel can be useful as a relative annual index while the jack mackerel biomasses estimated by echo integration are considered less reliable since are based on a length frequency sampling design that is directed to smaller and slower-moving fish like the anchoveta, and is not the most appropriate for jack mackerel.

The current records of echo-abundance of jack mackerel only provide estimates up to 2014 because the environmental conditions typical of El Niño in 2015 and early 2016 caused the anchoveta to be distributed very close to the coast and as a consequence the acoustic surveys were conducted with more frequency but were limited to areas much closer to the coast.

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.

Table 1.- Data used in the 2016 assessment

Type	Data	Details
From the fishery	Catch	1970 – 2016
	Catch-at-length	1980 – 2016
	Catch-at-age	1980 – 2016
	CPUE	2002 – 2014
	Selectivity	Dome shaped
Fishery independent	Echo-abundance	1985 – 2014
	Selectivity	Logistic
Biological	Growth parameters	k=0.165 y^{-1} , L_{∞}=80.4cm
	Natural mortality	M=0.33
	Maturity at age	First mat=2 y
	Weight at age	From updated W-L parameters

5.2.2 Joint Jack Mackerel model (JJM)

Different configurations were implemented in the 2016 assessment with the JJM model with the purpose of achieving the best representation of the population dynamics of the Peruvian (far-north) stock.

These various model configurations started from a base case (the 2015 configuration), using the *echo-abundance index* (S_A) and the CPUE from the industrial fishery to then progressively implement alternative configurations to consider:

- Adding updated information (group 0 models).
- Use of different time-breaks for the regime changes (group 1 models).
- Individual use of indicators (group 2 models)
- Different assumptions on the recruitment and productivity of the stock, (group 3 models).

All these configurations are summarized in Table 2.

The addition of updated information, either age compositions and 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 10a). 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 10b).

Small difference in magnitudes at the beginning and the end of the series of biomass were observed in the group 1 models where different time-breaks in regime change are analyzed (Figure 10c). As in the group 0 models, the mean value of estimated fishing mortality was very similar for all the configurations (Figure 10d). In the group 2 models the main purpose was to analyze the impact of the abundance indices available for this stock. The series of biomass showed similar trends and magnitudes (Figure 10e), while the estimated mean values of fishing mortality were slightly different but with similar distributions (Figure 10f).

The group 3 models were used to analyze the sensibility of the recruitment parameters, where the most important parameter to analyze was the *steepness*. The trends in biomass (Figure 10g) were very similar in the various configurations, while configuration 3.2 was the one that produced lower values of biomass and therefore the highest values of fishing mortality (Figure 10h).

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

Model	Description
Data update	
0.0	- As 2015 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 2016
Sensitivity in the regimes using different time-breaks	
1.0	As model 0.1
1.1	As model 1.0 but time - break in 1997 (two regimes: 1970 – 1996, 2001 – 2012).
1.2	As model 1.0 but time - break in 1998 (two regimes: 1970 – 1996, 2001 – 2012).
1.3	As model 1.0 but time - break in 1999 (two regimes: 1970 – 1996, 2001 – 2012).
1.4	As model 1.0 but time - break in 2000 (two regimes: 1970 – 1996, 2001 – 2012).
Sensitivity to biomass indices	
2.0	As in model 1.0
2.1	As in model 2.0 but using the new $CPUE_{\mathbf{industrial}}$
2.2	As in model 2.1 $CV_{\mathbf{CPUEindustrial}}$ = 0.3, and echo-abundance with CV = 0.3
Model configuration	
3.0	As in model 2.1
3.1	As in model 3.0 but steepness = 0.6.
3.2	As in model 3.0 but steepness = 0.8.

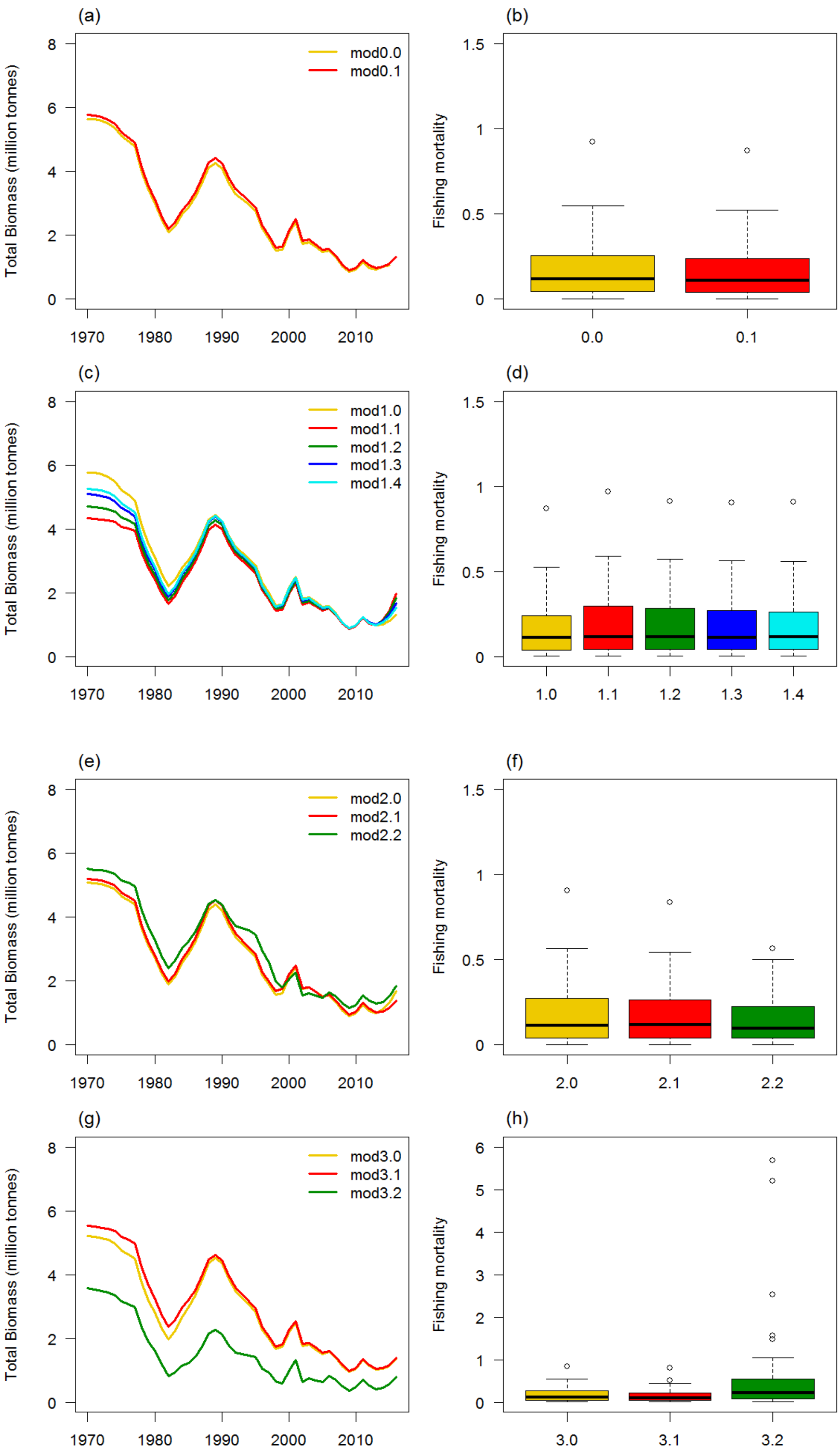

Figure 10.- Total biomass series and yearly fishing mortality distribution estimated for group 0 models (panels a & b, testing the sensitivity to updated data); group 1 models (panels c & d, testing the sensitivity to time-breaks in regime); group 2 models (panels e & f, testing sensitivity to abundance indices); and, group 3 models (panels g & h, testing the sensitivity to assumptions on recruitment productivity and stock-recruitment regime)

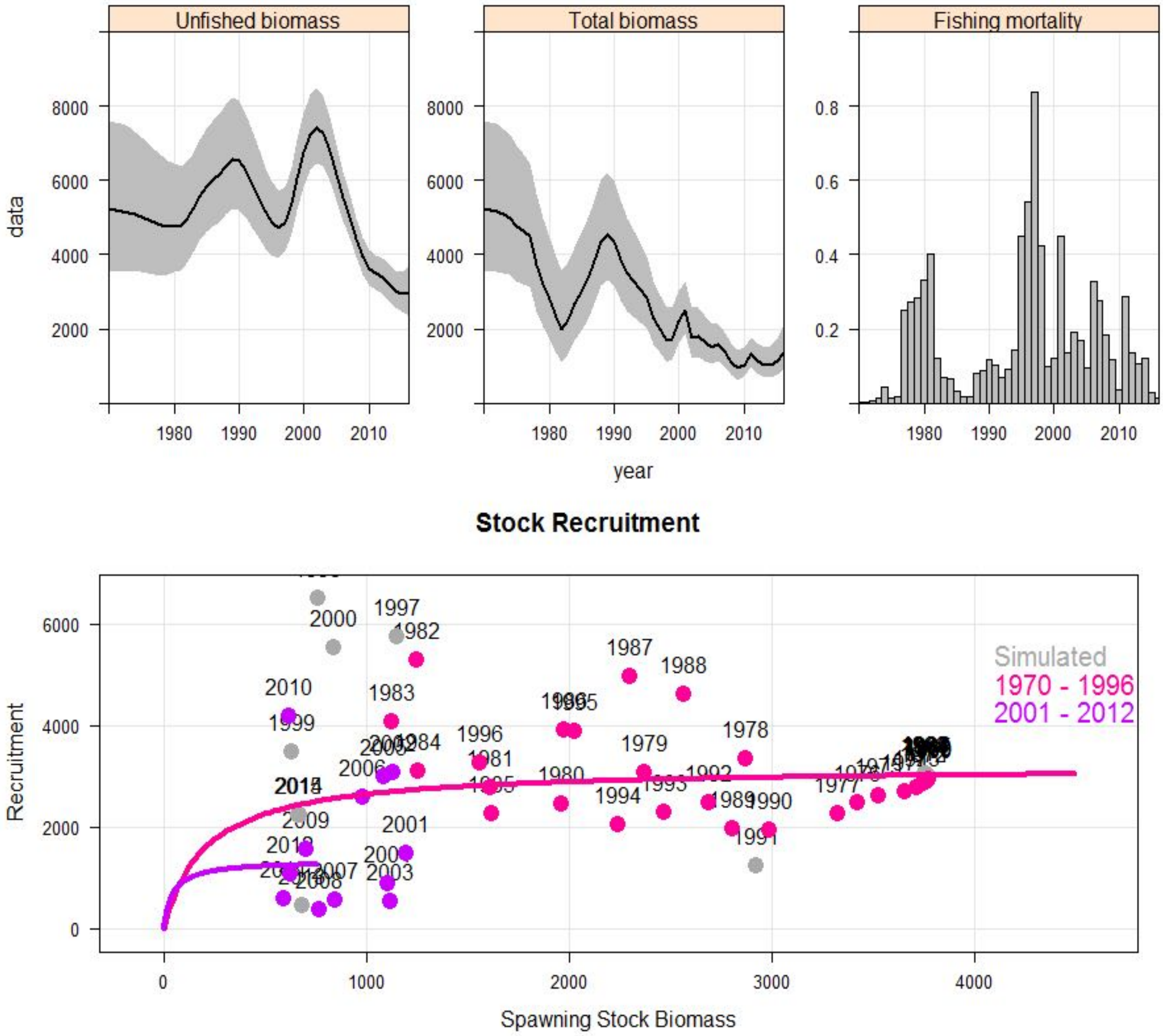

Figure 11.- Outputs of the final configuration showing the history and current situation of the Peruvian (far-north) stock. Unfished biomass, total biomass and fishing mortality are presented at the top panels. The stock-recruitment relationship showing two regimes is presented in the bottom panel

The outputs of the final configuration shows that the general trends in this 2016 assessment are very similar to those in the 2015 assessment, although the estimated final values of biomass are lower and the estimated fishing mortalities and corresponding estimates of risk that the projected biomass a year ahead be lower under the *status-quo* or other exploitation options are higher. In fact, the results of the selected final 2016 assessment configuration indicates that the *status-quo* (2015 conditions) could be achieved with an estimated risk of 9.62%, an $F_{status\text{-}quo}$ = 0.0259 and a TAC of 50,000 t, while a 50% higher estimated risk (of 14.4%) would correspond to a revised F_{rev1} = 0.0504 and a revised TAC_{rev1} = 93,000 t, exactly the same as the one in the 2015 revision. It is noted that the differences in some of the final magnitudes are mostly due to the use of two regimes and the new indices introduced this year.

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 11 and those of the stock and recruitment are presented in the lower panel in the same figure. As can be noted, the stock would have passed through two stages of productivity with high levels of total biomass during the 1990s and low levels at present. These two stages have been represented by two stock-recruitment regimes (Figure 11, 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 in account due to the high variability observed for those years, mainly induced by El Niño 1997-98 and probable instability caused by the regime change itself.

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