South Pacific Regional Fisheries Management Organisation

**1st Meeting of the Scientific Committee**

**La Jolla, United States of America, 21-27 October 2013**

**SC-01-13**

# Peru 2013 Annual Report (2) Areas under National Jurisdiction

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**South Pacific Regional Fisheries Management Organisation**
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**Peru National Report Nº 2**

# PERU

# NATIONAL REPORT ON THE SITUATION OF THE PERUVIAN STOCK OF JACK MACKEREL (FAR-NORTH STOCK) AND THE PERUVIAN FISHERY IN NATIONAL JURISDICTIONAL WATERS

**2013**

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## 1. INTRODUCTION

This report expands and updates the information and findings provided by the Peruvian delegation on the occasion of the 11th Meeting of the Science Working Group of the SPRFMO held in Lima, Peru, 15-19 October 2012 (IMARPE-PRODUCE, 2012). Particular emphasis is made here on the various aspects of the marine environment, the ecology, the biology, the fishery, the stock abundance, the assessments and fisheries management regulations that are particularly important, and in some cases unique to the Jack mackerel (*Trachurus murphyi*) in Peru. In so doing, proper reference is made to the most recent publication by Csirke *et al.* (2013) that compiles a selection of the most recent research work conducted at the Peruvian Institute of Marine Research (IMARPE) on the Peruvian Jack mackerel.

As already noted by Jordan (1983), Zuta *et al.* (1983), Serra (1983, 1991), Csirke (1995), Bertrand *et al.* (2008), Checkley *et al.* (2009) and others, large year-to-year variability as well as longer-term changes are common features of the marine environment, the fish abundance and total production of the main exploited species, including Jack mackerel, in the Southeast Pacific and particularly in the Northern Humboldt Current System that so strongly influences the Peruvian marine ecosystem. The variability in the marine environment and the biological and behavioral responses of the Peruvian stock of Jack mackerel (the far-north stock) are therefore dominant topics in this report. Other dominant topics are those related to the growth and ageing, reproduction and spawning, trophic interactions, and the observed changes in abundance, distribution and availability of the Jack mackerel stock in Peruvian and adjacent waters.

A point is also made regarding the multiple evidences that support the hypothesis of the existence of two or more stocks or subpopulations of Jack mackerel *T. murphyi* as proposed in the early 1990s by Serra (1991) and Arcos and Grechina (1994), and analyzed further in the context of the South Pacific Regional Fisheries Management Organization (SPRFMO 2008; Gerlotto *et al*. 2010 & 2012). The main hypothesis (Hypothesis No. 1) being considered by the SPRFMO (SPRFMO 2008) and others as the most viable is the one stating that *"Jack mackerel caught off the coasts of Peru and Chile each constitute separate stocks which straddle the high seas",* and is within this focus that this report emphasizes the main characteristics of the Peruvian Jack mackerel stock (the far-north stock) that mark the differences with the more southern stock(s) found off Chile.

## 2. THE MARINE ENVIRONMENT

One of the main world marine zones with the highest biological productivity is located off the occidental coast of South America, and this has a noticeable impact on all the trophic levels of the marine ecosystems in the area. The coastal 200 miles jurisdictional waters of Peru are part of this high productivity system that corresponds to the northern part of the Humboldt Current System (the Northern Humboldt Current System, NHCS). This area represents 0.1% of the world oceans but produces more than 10% of the world total fish catches (Chavez *et al*., 2008). This high productivity is mainly due to the very special physical characteristics of the Northern Humboldt Current System and particularly to the

presence of coastal upwelling cells, the large-scale dynamics and the meso and sub-mesoscale physical processes.

The large-scale dynamics of the Northern Humboldt Current System integrates several surface and sub-surface currents (Fig. 1) and is directly related to, and controlled by the Subtropical Anticyclone of the South Pacific.

This anticyclone gyre produces equator-ward winds that blow parallel to the South American coast, with average wind velocities that decrease from 8 m/s in the central zone of Chile to 4 m/s in the north of Peru. These winds parallel to the coast produce the offshore transport, known as Ekman transport (Ekman 1905), which originates coastal upwellings by carrying to the surface deep and cold water masses, rich in nutrients (Zuta & Guillén 1970, Pocklington 1981).

Current systems, water masses and patterns of variability off Peru are described by Flores *et al*. (2013), who note that the evolution in recent years of the sea surface temperature has a mid-term trend toward colder scenarios, favorable for the anchoveta (*Engraulis ringens*) but not so favorable for the development of the Jack mackerel stock.

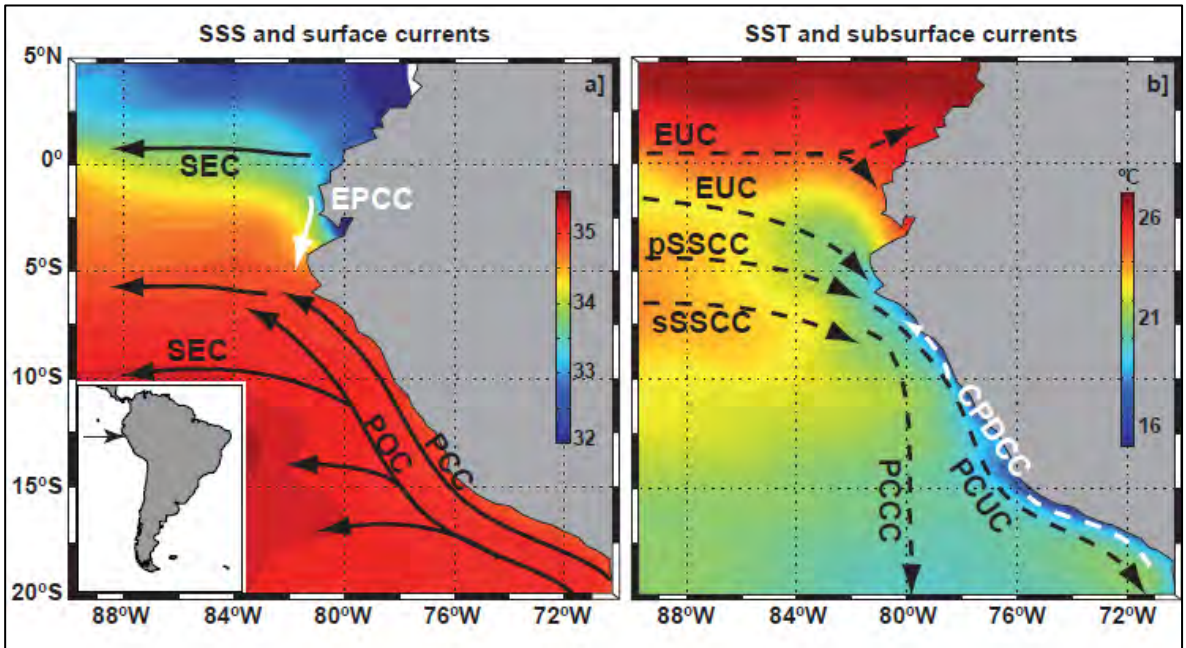


**Figure 1.** Sea surface properties and oceanic circulation scheme. (a) Sea-Surface Salinity (SSS, color shading) and surface circulation. (b) Sea-Surface Temperature (SST, color shading in °C) and subsurface circulation. SST and SSS were derived from the CARS 2009 climatology [Ridgway et al., 2002]. This Figure was adapted from *Penven et al.*, 2005; *Kessler*, 2006; *Montes et al.*, 2010; *Czeschel et al.*, 2011; *Mollier-Vogel et al.*, 2012. The newly defined Ecuador-Peru Coastal Current (EPCC) and Chile-Peru Deep Coastal Current (CPDCC) are indicated by white arrows.

Surface currents. SEC: South Equatorial Current; EPCC: Ecuador-Peru Coastal Current; POC: Peru Oceanic Current; PCC: Peru Coastal Current.

Subsurface currents. EUC: Equatorial Undercurrent; pSSCC: primary (northern branch) Southern Subsurface Countercurrent; sSSCC: secondary (southern branch) Southern Subsurface Countercurrent; PCCC: Peru-Chile Countercurrent; PCUC: Peru-Chile Undercurrent; CPDCC: Chile-Peru Deep Coastal Current.

**Figure 1. Oceanic circulation system off Peru (from Chaigneau *et al*. 2013).**

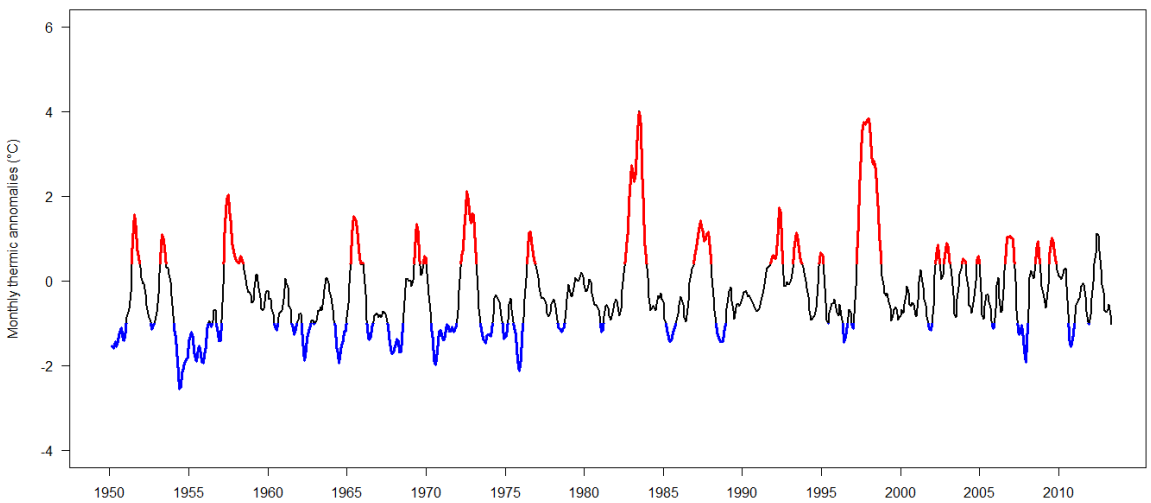


**Figure 2. Monthly thermic anomalies (°C) based on the Coastal Index of El Niño (ICEN) in the El Niño 1+2 region off Peru, years 1950-2013. El Niño (EN) conditions in red, and La Niña (LN) conditions in blue.**

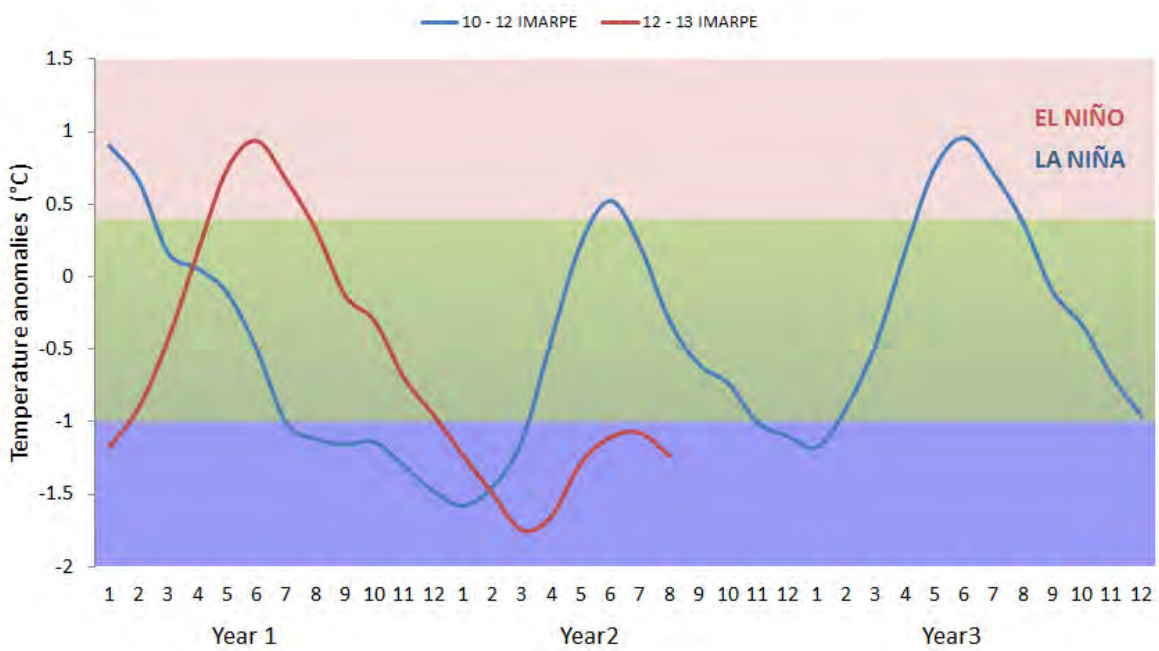


**Figure 3. Monthly averages of Sea Surface Temperature Anomalies (°C) for the whole Peruvian coast based on records from IMARPE´s Coastal Stations, for years 2010-2012 (blue line) and years 2012-2013 (red line).**

The National Technical Committee on the Study of El Niño Phenomenon (ENFEN) has developed an index to categorize short-term environmental conditions as El Niño (EN) or La Niña (LN). El Niño Coastal Index (ICEN) is the three-month moving average of anomalies of sea surface temperature (ASST) in the El Niño 1+2 region (between 00 – 10$^{o}$ S and 90$^{o}$ W – 80$^{o}$ W) in the Equatorial Pacific. These anomalies (Fig. 2) are calculated using the monthly climatology based on the period 1981-2010, of absolute SSTs v3b ERSST product of NOAA (USA) for El Niño 1+2 region (ENFEN, 2012). Accordingly, 2010-2011 and 2013 are defined as cold years characterized by the development of La Niña in Peru (Fig. 3).

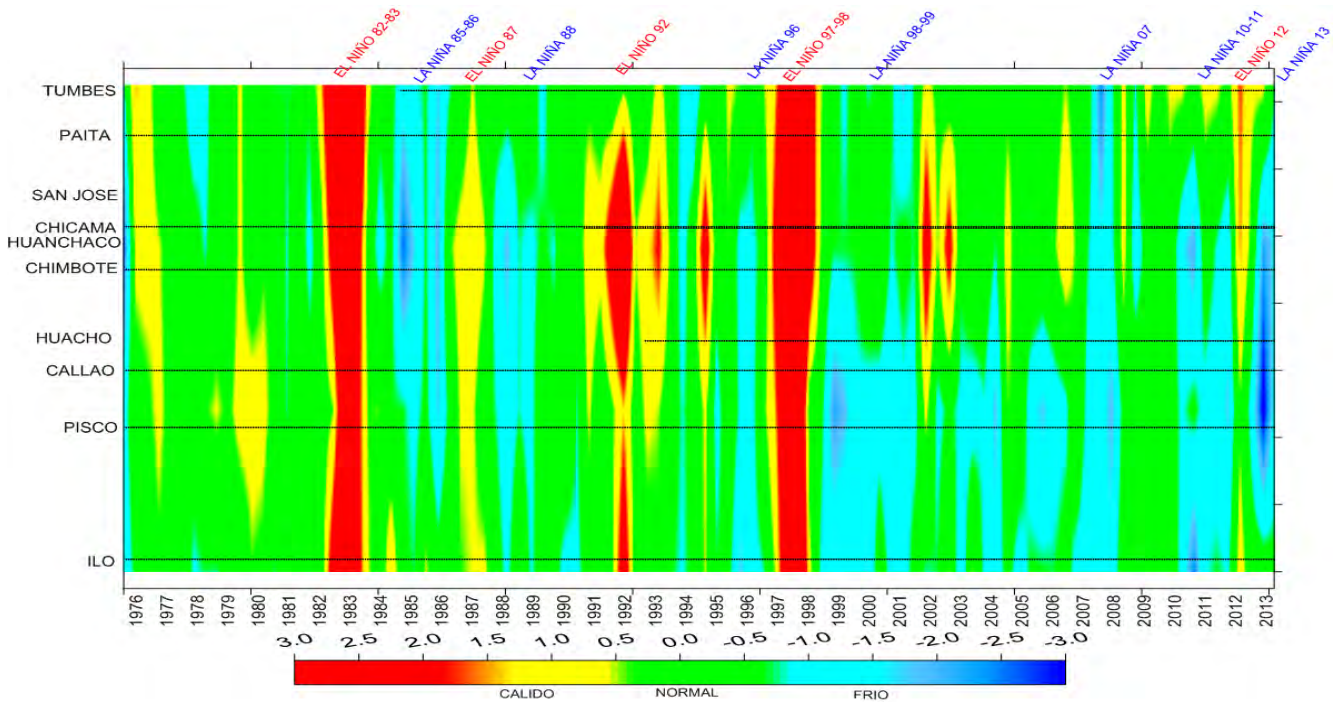


**Figure 4. Sea Surface Temperature Anomalies (°C) from IMARPE´s Coastal Stations, by latitude along the entire Peruvian coast, years 1976–2013.**

As can be noted in Figure 4, La Niña 2007 developed along the whole Peruvian coast and was the coolest event in the last 20 years. It had the lowest thermic anomaly (-3.4°C) in August–September, particularly in the area between 04°S and 06°S. In 2013, the whole year has been showing negative anomalies below -1°C (Fig. 3), with the lowest values in July-August in the central area of the Peruvian coast (Fig. 4), between Huacho (11°S) and Pisco (14°S).

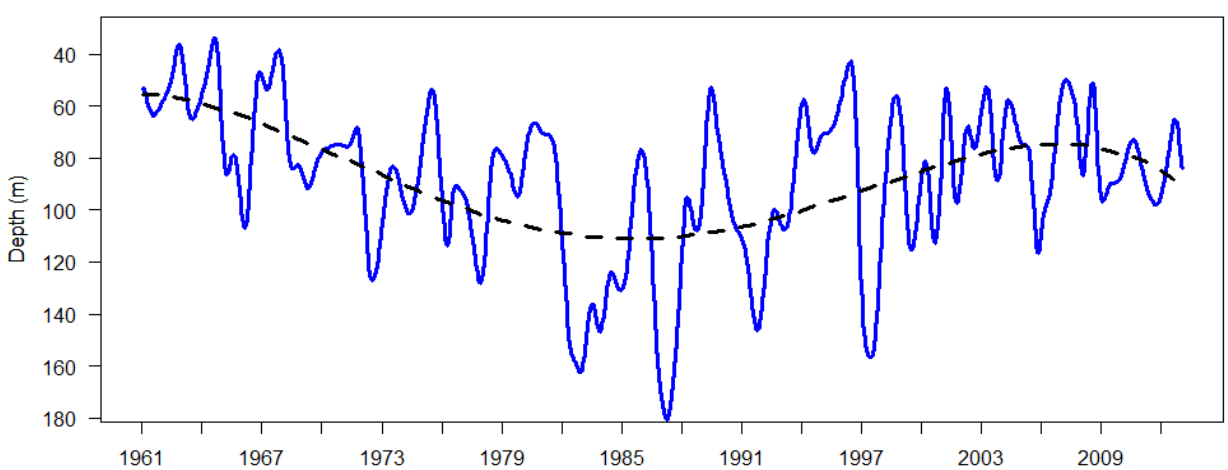


**Figure 5. Monthly values of the average depth of the 15°C isotherm for the three regions (North, Central and South) of the Peruvian coast, years 1961-2013.**

Some decadal patterns can be observed from the analysis of the changes in the depth of the 15$^{o}$C isotherm between 1961 and 2013 (Fig. 5). As can be noted, the 15$^{o}$C isotherm was shallower in the early 1960s, was deepening during the 1970s, was deepest during the decade of the 1980s and got shallower during the 1990s to reach the shallowest levels during the decade of the 2000s, completing a full interdecadal cycle in almost 47 years. As noted by Dioses (2013b), the depth of the 15 °C isotherm influences the vertical distribution Jack mackerel, and probably in the long run also influences its availability and abundance.

## 3. CHARACTERIZATION OF THE STOCK

There are evidences of major life cycle adaptive features of the Peruvian stock of Jack mackerel (*Trachurus murphyi*) to natural environmental fluctuations at different time scales typical of the Peruvian waters. The identification of the main stock responses to these changing driving forces may help to explain the observed dynamics of this population in the Peruvian waters and in the adjacent high seas, and may also help in guiding management decision regarding this fishery (Zuzunaga 2013). A brief review of these adaptive features follows.

### 3.1 Spatial distribution

The Peruvian Jack mackerel distribution expands over an extensive area that covers all the Peruvian jurisdictional waters and the adjacent high sea. This can be observed from the Peruvian Jack mackerel catches recorded during commercial fishing operations and scientific surveys conducted between 1980 and 2012 (Ñiquen *et al*. 2013, Dioses 2013b) as well as from the acoustic surveys conducted since 1983 (Segura & Aliaga 2013) and egg and larvae surveys conducted since 1966 (Ayon & Correa 2013).

Although there is abundant information on the environmental preferences and distribution response patterns of the Peruvian Jack mackerel in facing the already described changing environmental conditions, there are still uncertainties regarding the specific environmental or geographical features determining where the most likely separation between the Peruvian Jack mackerel stock (the far-north stock) and the Chilean stock(s) occurs. Albeit, it is noted that there are some indications suggesting that the most likely separation would be somewhere around the “Subtropical Convergence” described by Wyrtki (1967).

### 3.2 Differential characteristics of the Peruvian sea (habitat)

The complexity of the marine environment, its natural variability at different time scales and the probable consequences these may have for the development of the Peruvian Jack mackerel stock are extensively described by Flores *et al.* (2013) and Espino (2013). The main conclusions of these studies are that there are enough scientific evidences to support that environmental stress is the main trigger of the observed large changes in Jack mackerel abundance and availability in the Peruvian jurisdictional waters and in the adjacent high sea. The analyses of the various environmental and biological signals contribute to explain the drastic decline in abundance towards the end of the 1990s implied by the results of the acoustic estimates (Segura & Aliaga 2013), which took place

in the absence of any significant fishing pressure and very low catches in the 1980s and 1990s (Fig. 6). The work by Flores *et al.* (2013) and Espino (2013) show that long-term changes in the distribution pattern of the Sea Surface Temperature in Peruvian waters have by themselves noticeable impacts on the Peruvian Jack mackerel stock, as suggested by the tight parallelism between the decline of the area covered by warm isotherms (22°C-25°C) and the acoustic biomass estimates since mid-1990s in Figure 6.

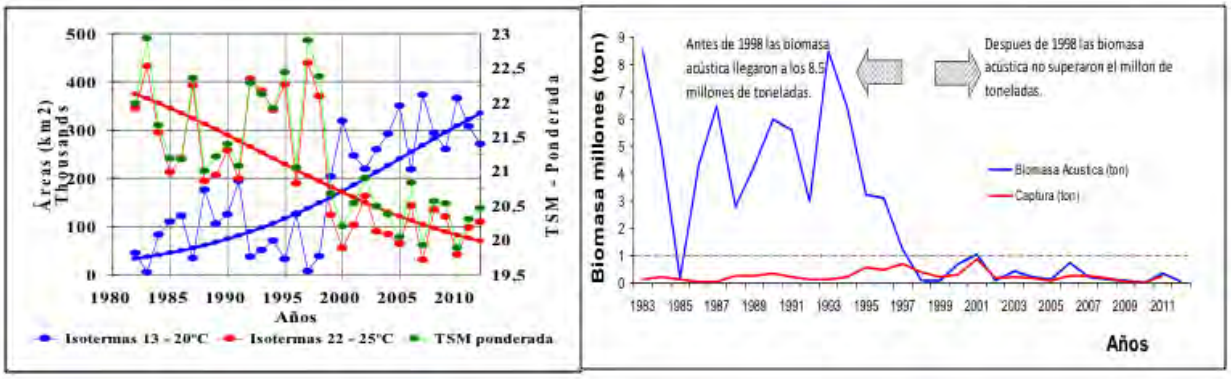


**Figure 6. Left: Distribution of the areas covered by two sets of isotherms (13-20°C in blue, and 22-25°C in red) in the Peruvian jurisdictional waters and the adjacent high sea (02°N-20°S and 68-85°W) and Weighted Average Sea Surface Temperature (WASST/TSM in green), by year, 1982-2012 (From Espino 2013). Right: Annual catch (red line) and trend of acoustic estimates of Jack mackerel biomass (blue line), by year, 1983-2012 (From Segura & Aliaga 2013).**

## 3.3 Age and growth

A combination of several approaches has been followed in the age and growth studies of the Peruvian Jack mackerel undertaken in recent years by IMARPE. These include: conventional interpretation of annual marks in otoliths (Dioses 2013a); counting daily increments of the first annuli in otoliths and following the growth of the second annuli in otoliths of one cohort along more than one year (Goicochea *et al.* 2013); and, analyzing monthly length frequencies to estimate growth parameters (Díaz 2013). The results of all these studies were strongly congruent confirming the estimates of the parameters of the von Bertalanffy growth function for the Peruvian Jack mackerel in use since the 1990s (Fig. 7A), where: $L_\infty$ = 80.77 cm total length, k= 0.1553 year$^{-1}$ and $t_o$ = -0.3562 (Dioses 1995, 2013a).

On this, it is worth noting that the samples analyzed by Dioses (2013a) were from 1977 and 1978, while those analyzed by Goicochea *et al*. (2013) were from 1995 and 2011, suggesting a persistence of these traits along time while confirming the validity of the early IMARPE age readings. It is also relevant to note that Dioses (2013a), Goicochea *et al.* (2013) and Díaz (2013) conclude that the values of the parameters for the Peruvian Jack mackerel are different from those estimated by other authors for the Jack mackerel in Chile and in the Southern Pacific high seas (Fig. 7B).

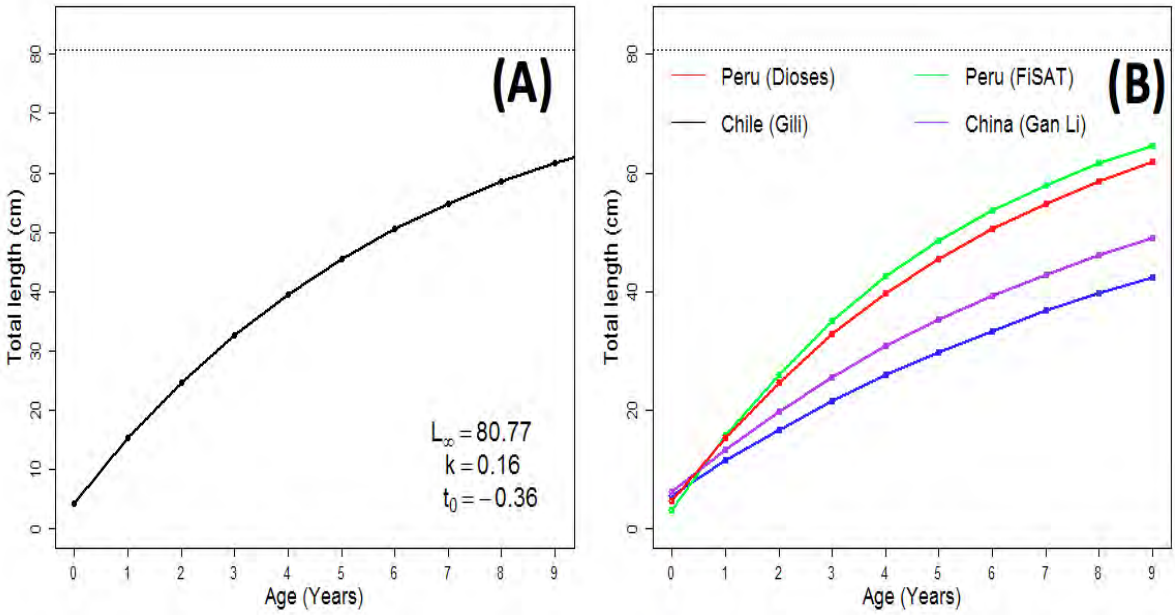


**Figure 7. (A) Growth curve of Peruvian Jack mackerel (after Dioses 1995 & 2013a). (B) Comparison of the growth curves of Peruvian Jack mackerel (broken green and continuous red lines), Chilean Jack mackerel (bottom black continuous line) and Jack mackerel in the Southern Pacific high seas (purple broken line) (after Goicochea *et al.* 2013)**

### 3.4 Reproductive aspects

Recent reproductive studies on the Peruvian Jack mackerel have been conducted by Perea *et al.* (2013) and Sanchez *et al.* (2013) with samples and data from 1967 to 2012. The size at first maturity has been estimated in the range of 25-27 cm total length, equivalent to an age of 2 years. One important observation from these analyses is that this size at first maturity has remained nearly unchanged throughout the observed period (1967-2012) in spite of the observed large and long-term environmental and stock size changes. This can be interpreted as an additional indicator that the fishing effort exerted on this Peruvian stock has been maintained well under the threshold that would have caused a juvenilization of the stock, with changes in the growth parameters typical of some overexploited stocks.

The spawning cycle of the Peruvian jack mackerel extends from August to February, with a peak in November (Perea *et al.* 2013). This cycle is out of phase with that observed for Jack mackerel off the Chilean central-southern region, whose spawning cycle is much shorter and peaks higher in December (Fig. 8). The spawning activity of the Peruvian Jack mackerel is strongly influenced by the high environmental variability typical of this part of Southeast Pacific. In this respect, it is noted that it is not surprising that different stocks and species would adapt the timing and/or duration of their spawning season to maximize the matching of their spawns with the time windows or time periods with the lower environmental uncertainty and higher probability of survival for their eggs and larvae. Therefore, the more flatten and extended spawning period of the Peruvian Jack mackerel

and the observed asynchrony in the peak of the spawning period with that of central-southern Chile might be the result of a different response to different environmental regimes and associated variability.

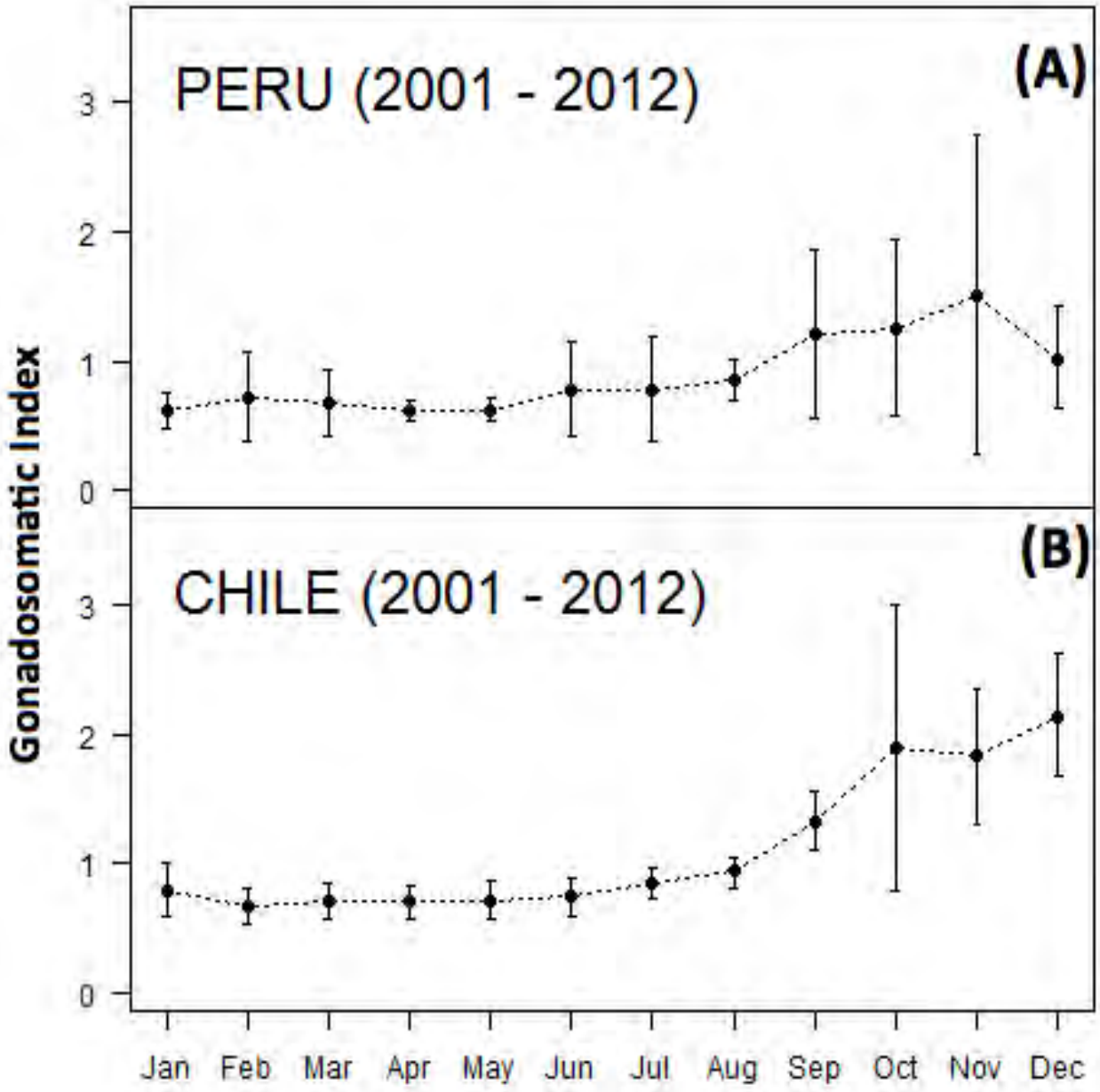


**Figure 8. Spawning cycle of Jack mackerel in Peru (A) and in Central-Southern Chile (B) (From Perea *et al.* 2013).**

### 3.5 Spawning areas

Ayón & Correa (2013) analyzed data and samples of eggs and larvae collected for more than 40 years and confirmed the constant presence of Jack mackerel larvae in Peruvian waters and the adjacent high sea throughout the whole observed period and along the entire coastline (Fig. 9), with some variations between decades in response to changes in the climatic regime. The results of these analyses by Ayón & Correa (2013) showing that the Peruvian waters and the adjacent high seas are a permanent spawning ground for Jack mackerel match the observations of the more flatten and extended spawning period of the Peruvian Jack mackerel made by Perea *et al.* (2013). The matching of these two pieces of information is of particular interest considering the high productivity of Peruvian waters with the existence of the appropriate spatial heterogeneity as evidenced by the presence of points of eddy genesis (Chaigneau, *et al.* 2008), which are fertilization centers in the ocean that retain and transport a variety of marine organisms, such as spawning products (eggs and larvae), and thus reducing the offshore transport, increasing larval retention and probably larval survival.

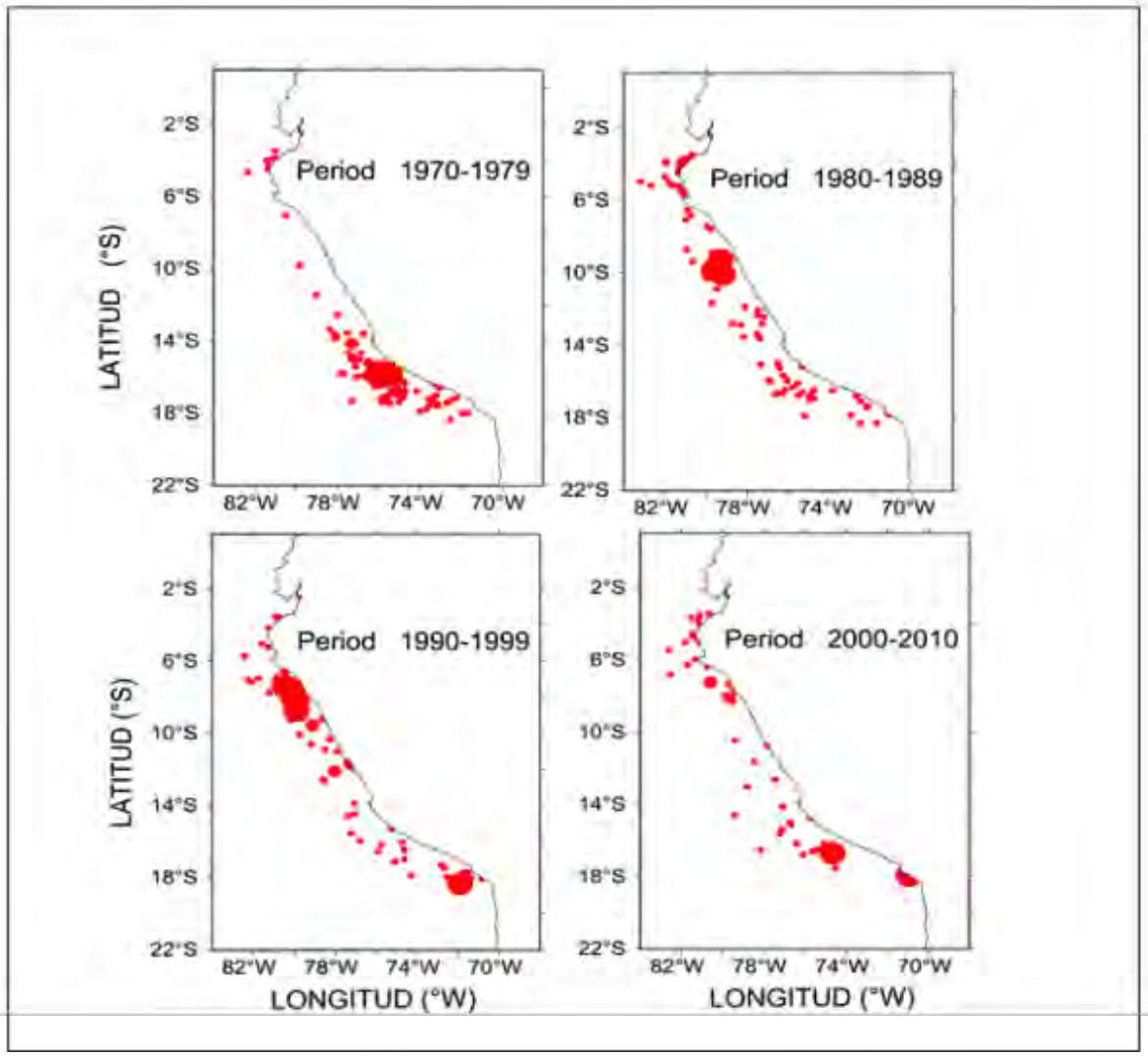


**Figure 9. Spawning centers of Peruvian Jack mackerel (1970 – 2010).**

### 3.6 Trophic relationships

The recent analysis of food content of Jack mackerel (Alegre *et al.* 2013) provides a complete spectrum of its diet. Jack mackerel is a species whose diet has a great diversity of preys, with predominance of euphausids. Two food content scenarios are identified by Alegre *et al.* (2013), the a warmer 1977-2000 period with a stronger dominance of euphausids and a colder 2000-to-date period with a greater diversity of prey, composed mainly by euphausids, but also some squat lobster and zoeas (Fig. 10). Overall, euphausids dominate the diet of Jack mackerel and it is noted that this euphausids are the most abundant components of the zooplankton community in the Peruvian waters (Ayón *et al.* 2011). However there are some differences by size, since it has been noted that smaller/younger individuals have a relative higher proportion of copepods in their diet (this group is indicator of Surface Subtropical Waters), while larger/older individuals consume a relative higher proportion of mesopelagic fish. It is noted that in general, Jack mackerel is a facultative and opportunistic predator in the Peruvian pelagic ecosystem, feeding on both the neritic as well the oceanic epipelagic environments, which allows it to respond and adapt to distinct environmental conditions and variations.

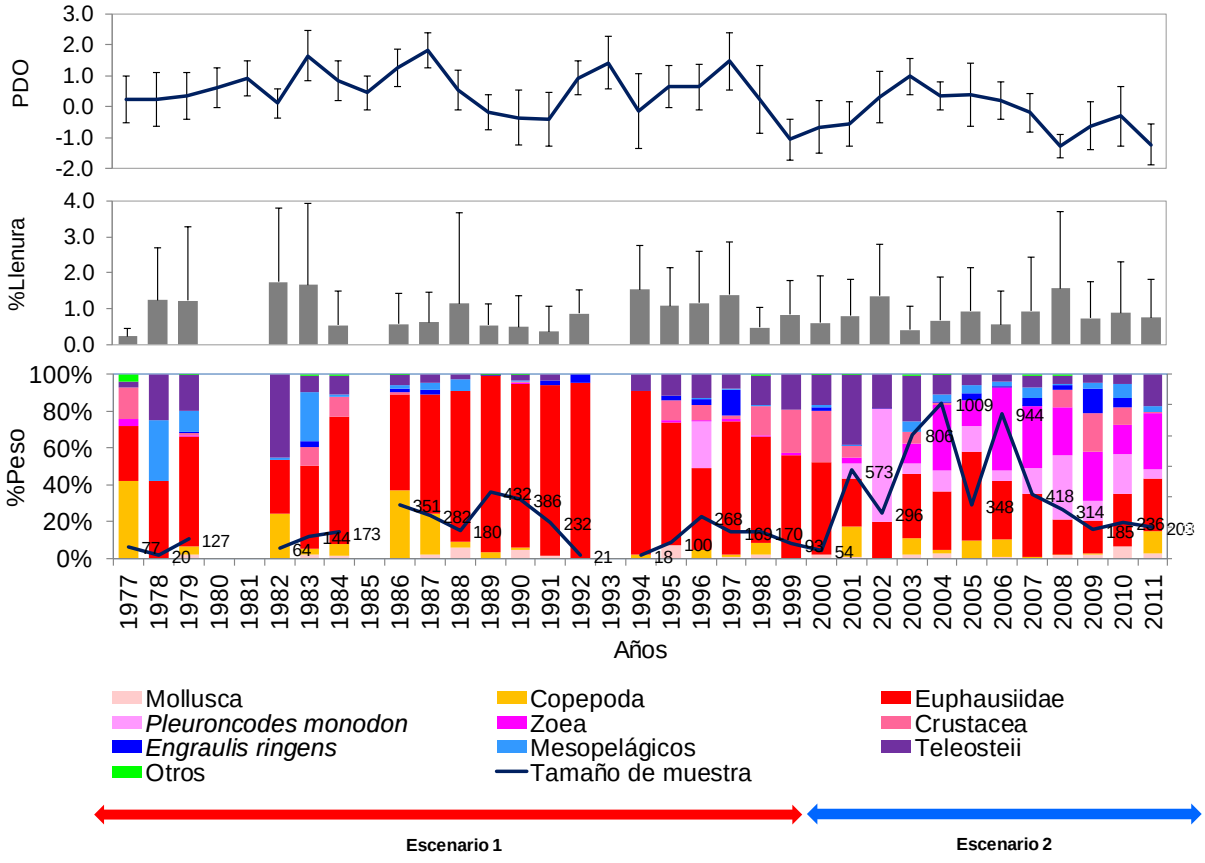


**Figure 30. Pacific Decadal Oscillation index (PDO), Index of fullness (% Llenura) and proportion of prey (% Peso) in stomachs of Jack mackerel *T. murphyi* off Peru from 1977 to 2011.**

## 4. DESCRIPTION OF THE FISHERY

The Jack mackerel sustains one of the most important fisheries in Peru. The Peruvian jack mackerel fishery produced up to 9% of the total Peruvian landings in the late 1990s and early 2000s, and even if this share has gone down to 1 to 4% in more recent years the Jack mackerel still represents the third most important species in terms of catch volumes landed, after the anchoveta and the jumbo squid (*Dosidicus gigas*)

One result of the fisheries management regulations in force in Peru has been the reduction in the number of vessels and overall hold capacity of the fleet licensed to fish Jack mackerel in Peruvian waters, to 104 vessels with a total hold capacity of 33 359 $m^3$ in 2011. Of these, 62 are industrial steel purse seiners with a total hold capacity of 30 177 $m^3$, and 42 are smaller wood purse seiners with a total hold capacity of 3 082 $m^3$.

### 4.1 Catch trends

In 2011 and 2012 there has been a recovery in the availability of Jack mackerel in Peruvian waters, which reverses the declining trend observed since 2006-07 that got to its minimum in 2010 with a total landing only 17 559 tonnes, the lowest on record in recent years (Fig. 11). Since then landings have increased to 257 241 and 168 779 tonnes respectively in 2011 and 2012.

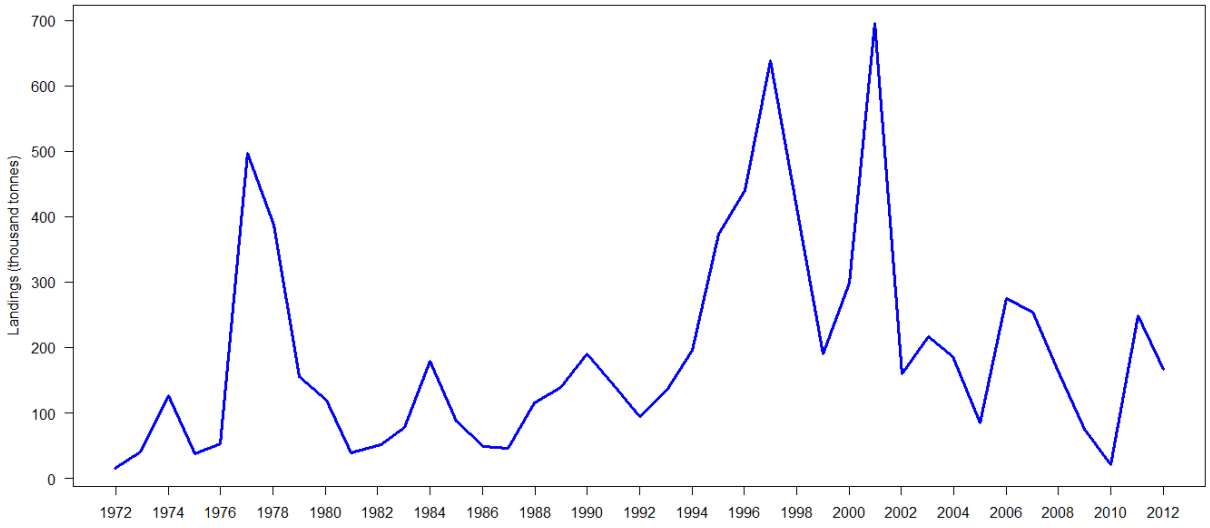


**Figure 11. Annual landings of Jack mackerel *T. murphyi* in Peru during 1972-2012.**

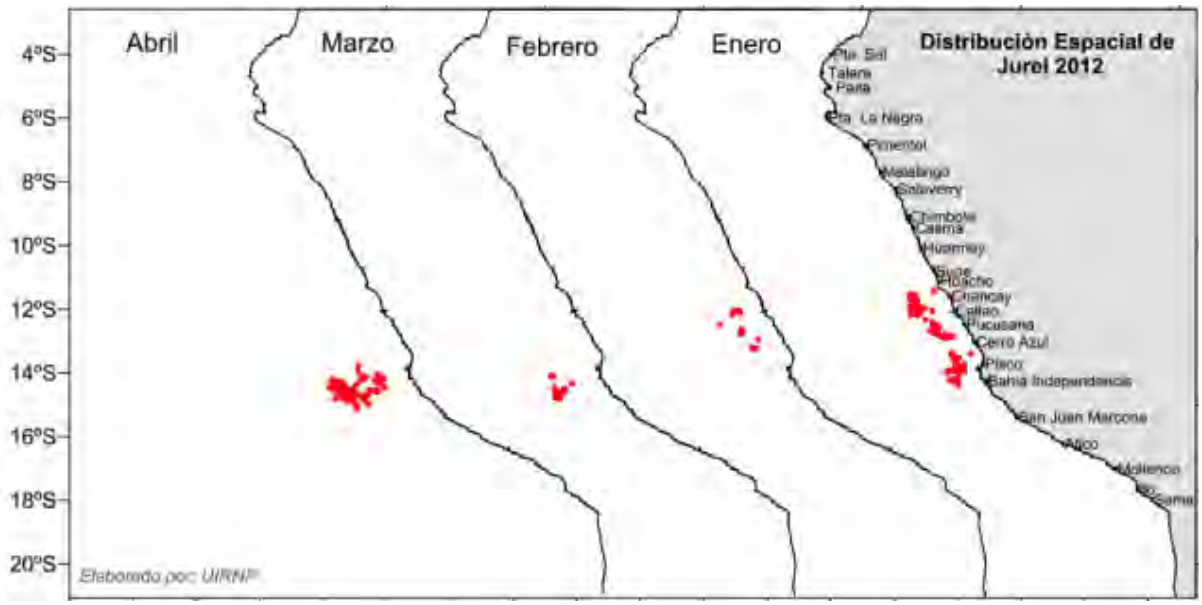


**Figure 12. Geographic distribution of the main fishing areas of Jack mackerel, by month from January to April 2012**

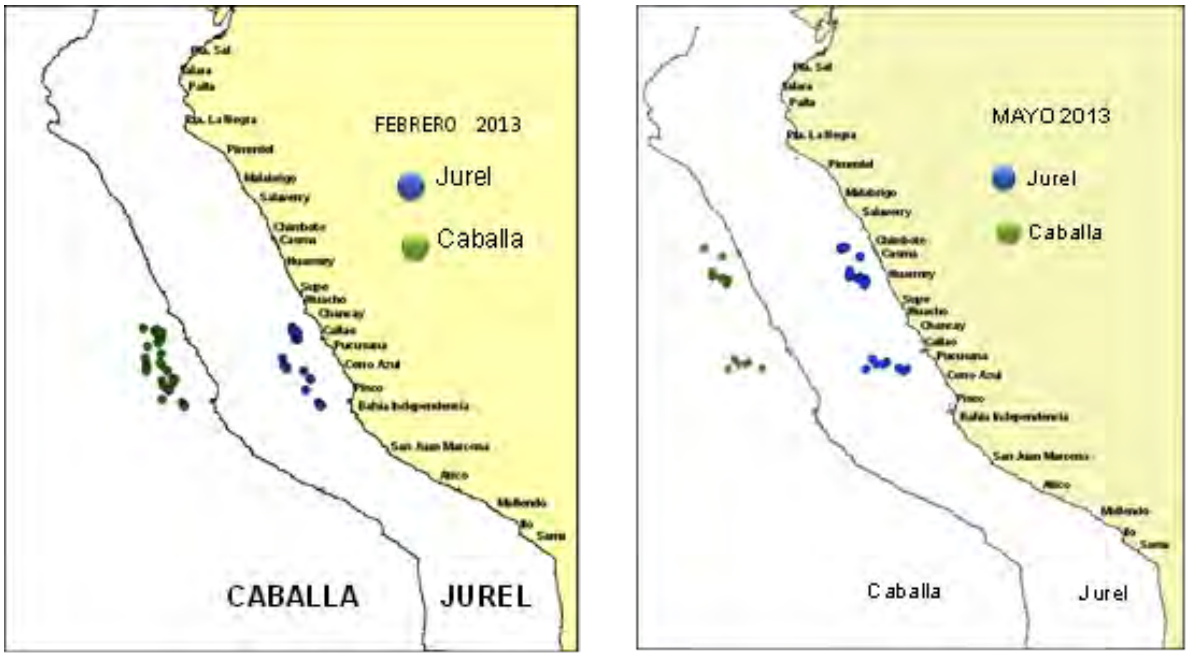


**Figure 13. Geographic distribution of the main fishing areas of mackerel and Jack mackerel in February and May 2013.**

During January-April 2012 the catches of Jack mackerel were mostly concentrated in the area south of Chancay (11°30'S) with a slightly more southern and offshore distribution in April (Fig. 12). This was a much more restricted distribution of the catches in comparison to 2011, when catches were landed almost along the whole Peruvian coast, from Talara (04°34' S) to Ilo (17°36' S).

In 2013 (until June), the industrial fleet caught only a total of 27 000 tons of Jack mackerel and the main landing ports were Callao (12°S) and Chimbote (09°S). During February 2013, the industrial fleet operated from Chancay (09°30´S) to Bahia Independencia (14°30´S), mainly between 50 and 100 miles from the coastline (Fig. 13). In May there were two zones of concentration, one off Huarmey (10°S) and another off Callao (12°S). No commercial fishing activities for Jack mackerel have been reported from May to-date, due to the low availability of Jack mackerel driven by the prevailing cold environmental conditions.

During February-May 2013, the industrial fleet operated from Chimbote to Bahia Independencia, mainly between 50 and 100 miles from the coastline and caught caballa (*Scomber japonicus*) in almost the same areas and most times together with Jack mackerel (Fig. 13). In May there were two main concentration areas of these two species, one off Huarmey (10 ° S) and the other off Callao (12 ° S).

### 4.2 Size structure

During the whole 2012 there was a continuous presence in the catches of the purse seine fleet of a strong cohort or group of adult Jack mackerel with modal lengths between 38 and 42 cm (Fig. 14), with two much younger groups appearing in the second part of the year.

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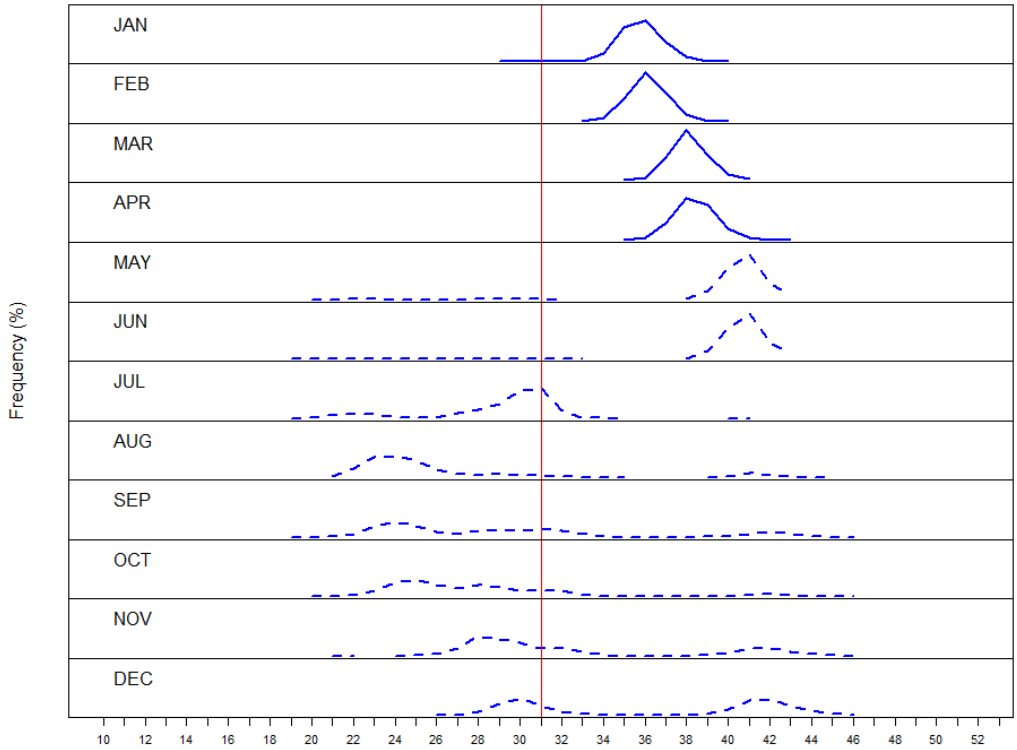


**Figure 14. . Size frequency distribution of Jack mackerel caught by the industrial (solid line) and artisanal (broken line) purse seine fleets, by month, January – December 2012.**

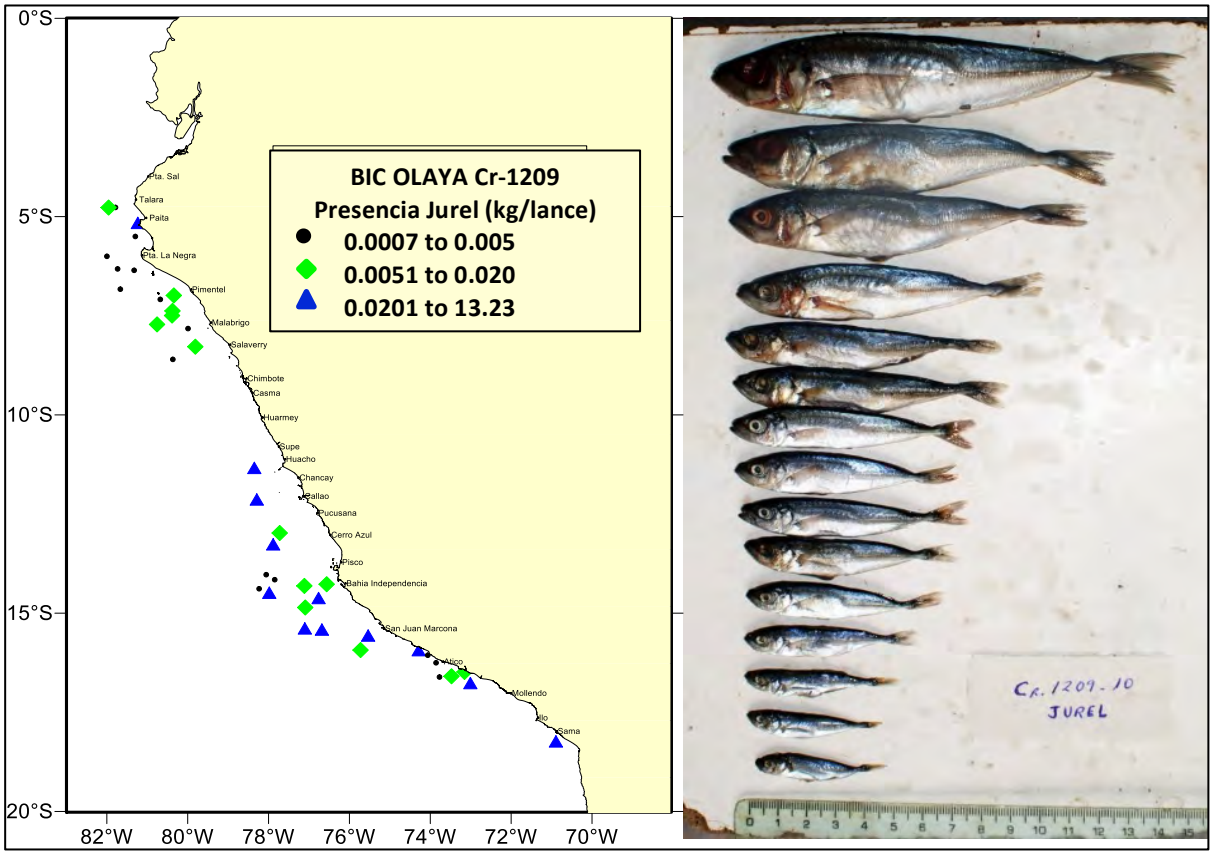


**Figure 15. Geographical location and amounts in kg/tow (left figure) and size range (right figure) of juveniles of Jack mackerel observed during the BIC Olaya survey of September 2012.**

The IMARPE scientific survey conducted in September and October of 2012 provided valuable information on the Peruvian Jack mackerel general distribution and on the presence of juveniles (IMARPE, 2012b). The Jack mackerel was found to have a wide and scattered distribution in the explored area (from 0 to up to 130 miles from the coastline, along the whole coast), forming isolated patches. The areas with Jack mackerel showed an important overlap area with the areas with anchoveta, with the two species being found together in 18% of the catch sets made. Shoals of Jack mackerel were detected from Talara (4°S) to Mollendo (16°S), and from 0 to more than 120 nautical miles from the coast. The higher density nuclei were found 60 miles off Pimentel (07°S) and 40 miles off Huacho (11°S).

This wide distribution was characterized by the dispersed but widespread presence of groups of juveniles (Fig. 15). These juveniles were of various sizes, ranging from 2 to 17 cm in total length, with three clear modal groups: at 8 cm, 12 cm and 17 cm. This significant presence of juveniles has not been seen off Peru in a long time, probably since the period of the large Jack mackerel population increase between 1975 and 1978. Later in November and December, these juveniles were recorded as by-catch in the anchoveta fishery in the north-central region (Ñiquen & Dioses, 2013).

The monthly size frequency distribution of the Jack mackerel caught in Peru by the commercial fleet during the first half of 2013 is shown in Figure 16. The size range in the catches goes from 27 to 44 cm total length, with at least two modes in 33 cm and 44 cm corresponding to adult individuals during January-March (summer) and a group of smaller individuals with modes in 29 cm and 31 cm in May (fall). The scientific survey conducted this year by IMARPE during the austral summer found two groups of juveniles, one in the range of 3 to 9 cm total length and another in the range of 17 to 23 cm.

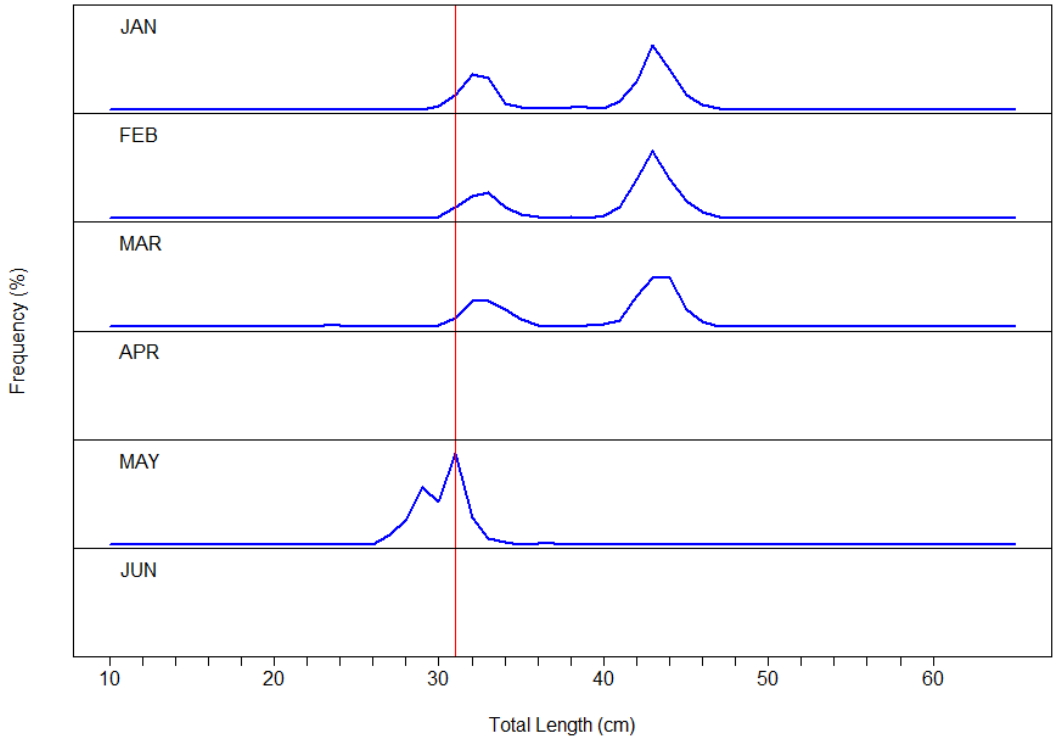


**Figure 16. Size structure of Jack mackerel caught in Peru during January – June 2013**

## 5. STOCK ASSESSMENT

### 5.1 2012 assessment and 2013 TAC

In January 2013 IMARPE made an assessment (2012 assessment) of the Peruvian Jack mackerel stock (far-north stock) in order to advice to the Peruvian Vice-Ministry of Fisheries on the current stock situation and the estimated Total Allowable Catch for 2013. This assessment was undertaken using the last version of the Joint Jack Mackerel (JJM) model developed during the 11$^{th}$ Science Working Group Meeting held in Lima in October 2012. Model inputs included, among others: catch-at-length series from 1980 to 2011, growth parameters, sexual maturity ogive, and M estimations for the Peruvian stock. Lambda values used for the log-likelihood functions are the same than those specified in the last SWG report (Tables 1, 2 & 3).

**Table 1. Jack mackerel sexual maturity by age used in the JJM model.**

| Age (yr) | 1 | 2 | 3 | ≥4 |
|---|---|---|---|---|
| Far-north stock | 0.00 | 0.37 | 0.98 | 1.00 |

**Table 2. Growth parameters and natural mortality for the Peruvian Jack mackerel stock.**

| Parameter | Values |
|---|---|
| $L_\infty$ (cm) (Total length) | 80.77 |
| k | 0.16 |
| $t_0$ (year) | -0.356 |
| M ($year^{-1}$) 0.33 | |

**Table 3. Years and types of information used in the assessment.**

| Fleet | Catch age | at Catch length | at Landings | CPUE | Acoustic | DEPM |
|---|---|---|---|---|---|---|
| Far-north | - | 1980-2012 | 1970-2012 | 2002-2012 | 1983-2011 | - |

The model results based on the 2012 assessment suggested that the spawning biomass for the Peruvian stock (far-north) was 316 000 tonnes (January 1st 2013). This value is 119% higher than the estimated in the same model for 2012 and 47% higher than the average 2000-2012 (Fig. 17).

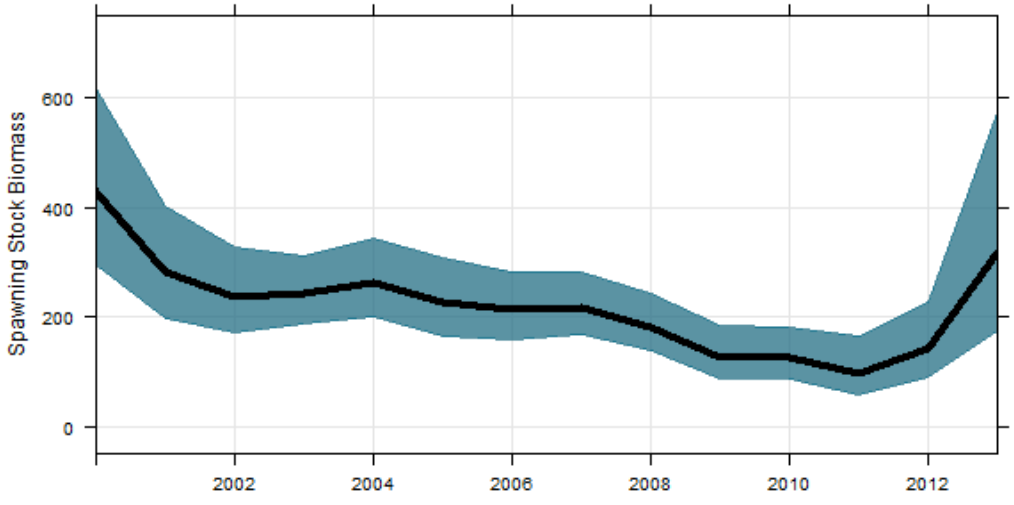


**Figure 17. Spawning stock biomass estimated in the 2012 assessment for the Peruvian (far-north) stock, by year, 2000-2013.**

The stock size estimated at January 1st 2013 was further projected 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 2014 was not lower than that estimated for 2013. Assuming a conservative risk of 10%, the estimated TAC was 133 000 tonnes (Fig. 18). The above TAC was included in the recommendations, together with a proposal for an intensified monitoring of the fishery and of the environmental conditions to ensure early detection of possible non-foreseen changes.

The preliminary TAC established by the Vice-Ministry of Fisheries at the beginning of the year was 80 000 tonnes, and as of August 2013 the industrial fleet has taken only 33% of this allocated TAC. All seems to indicate that the fleet has fallen short in taking the allocated TAC mainly due to changes in the distribution pattern and lower availability of the Peruvian Jack mackerel. As explained by Espino (2013), Flores *et al.* (2013) Dioses (2013) and in earlier sections of this report, these changes in distribution and availability are associated with La Niña conditions, which have developed in the course of the year and are causing the Jack mackerel to be more dispersed and farther offshore. The increased distance from the coast and the lower concentration of shoals make it more costly and less attractive for the fleet to fish for Jack mackerel under the current conditions.

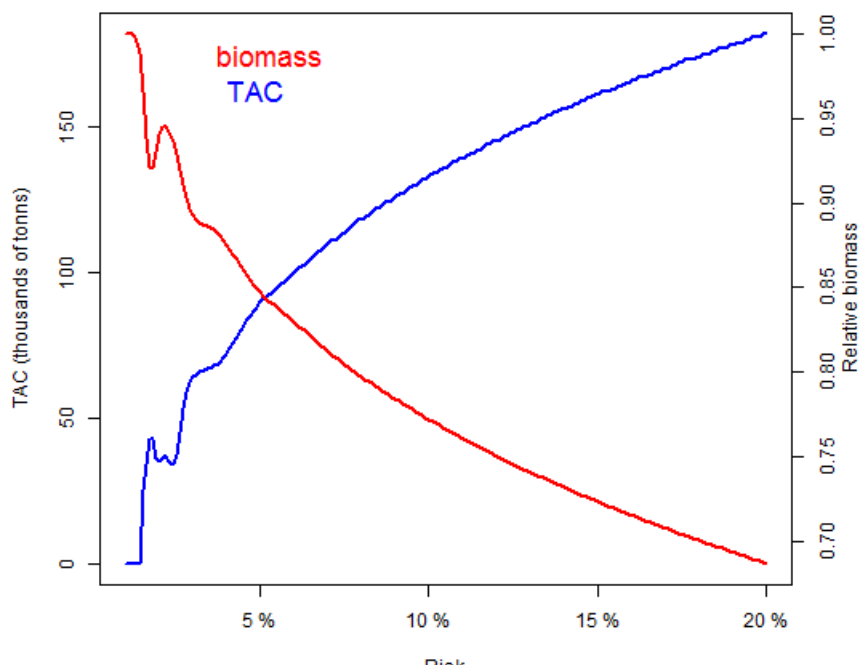


**Figure 18. Biomass predicted in the 2012 assessment by the JJM model for 2014 under different TAC scenarios and associated risk.**

### 5.2 2013 assessment

An updated assessment was conducted for the Peruvian (far-north) Jack mackerel stock during the second half of 2013. Improved versions of CPUE (Fig. 19) and acoustic (Fig. 23) indices were calculated and used for the calibration.

The CPUE was standardized (Fig. 19) using a GAM model, allowing us to include non-linear relationships among the explained and explanatory variables. The independent variable (catch by trip) in a monthly scale was previously normalized using the Box-Cox transformation and modeled using time (Gregorian), month, hold capacity, latitude, and distance to the coast as explanatory variables. The standardized CPUE was estimated fixing the hold capacity, latitude, and distance to the coast to the median value and the month to March, assuming the continuous time captures the variability in the abundance of Jack mackerel.

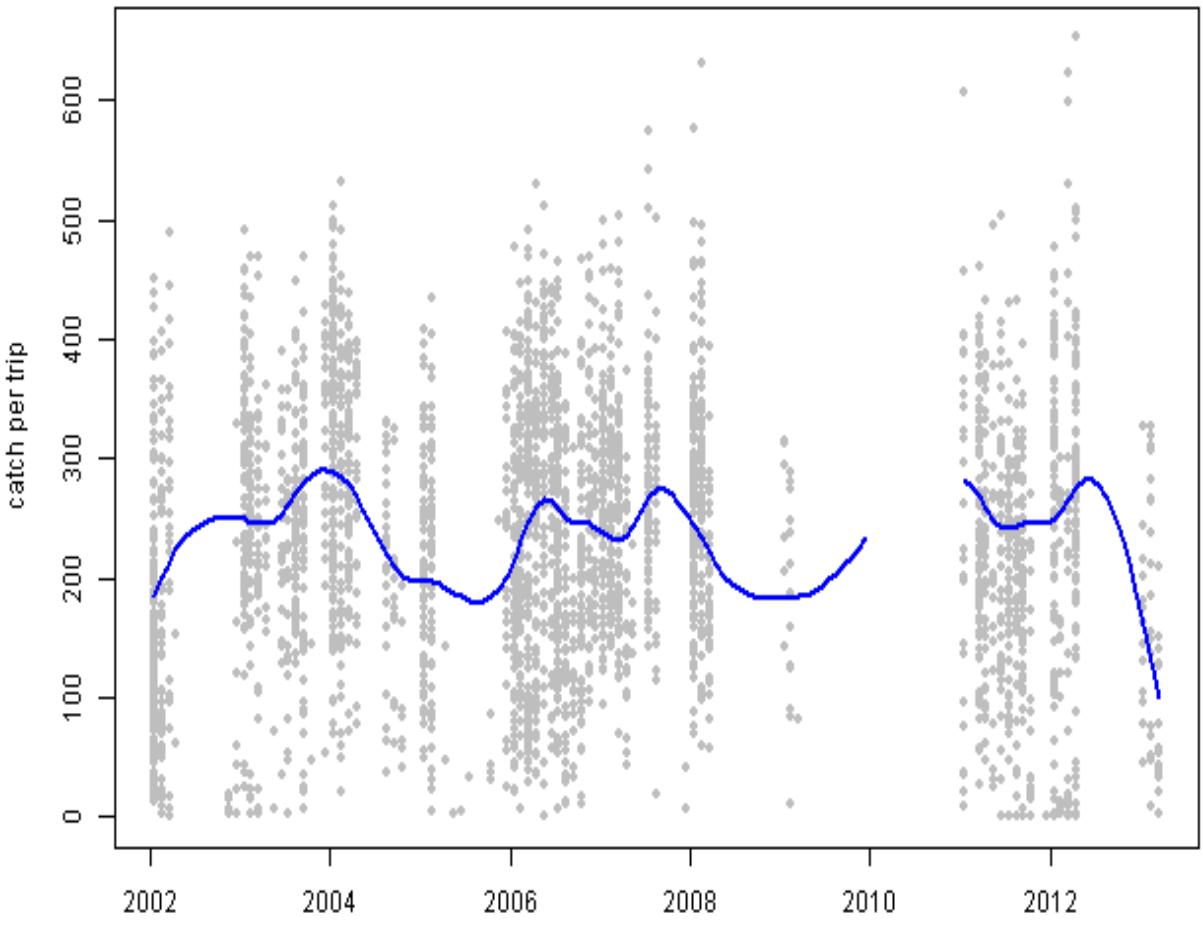


Figure 19. Standardized CPUE for the Peruvian Jack mackerel (far-north) stock.

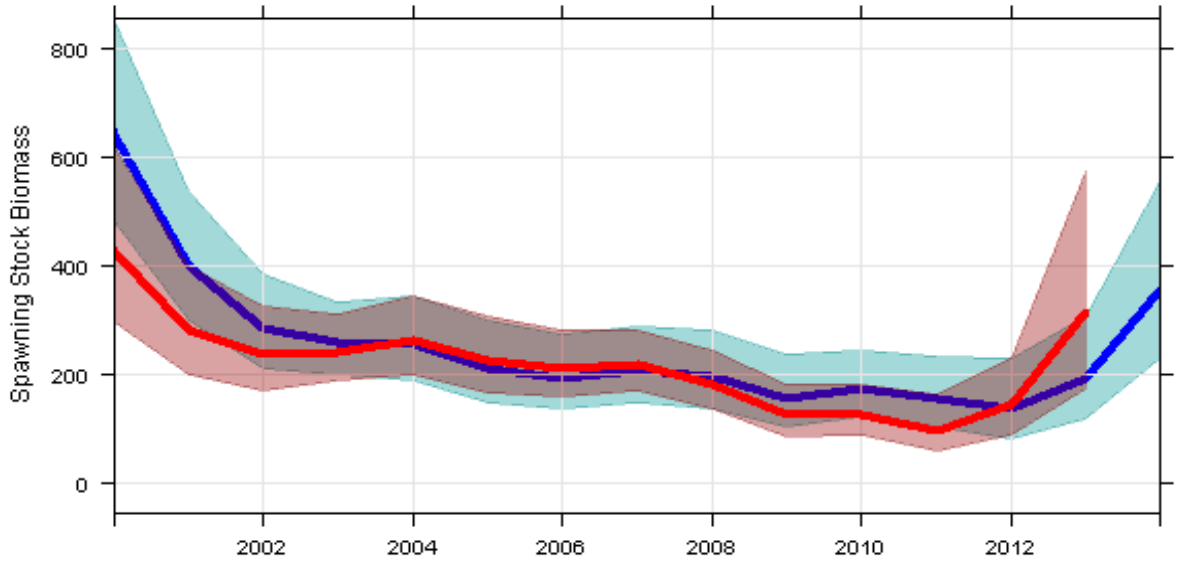


**Figure 20. Spawning stock biomass estimated for the Peruvian (far-north) stock by the 2012 assessment (red line) and the 2013 assessment (blue line) by year, years 2000 to 2013.**

These 2013 assessment results suggest that the spawning biomass of the Peruvian (far-north) stock (January 1st 2013) was 191 000 tonnes. This value is 38% higher than the estimated for 2012 by both the 2012 and the 2013 assessments, is 25% lower than the estimated average for 2000-2012 and is 40% lower than what was estimated for 2013 by the 2012 assessment (Fig. 20).

## 6. FISHERIES MANAGEMENT REGULATIONS

The legal framework for the conservation and sustainable use of Jack mackerel fisheries in Peru is widely described by Zuzunaga (2013). This paper describes the various fisheries management regulations adopted by the Government until 2012 considering the Jack mackerel distributed in Peruvian jurisdictional waters and the adjacent high sea as a self contained independent stock unit, which can be properly managed under the regulations established by the Peruvian Fisheries Management Regulation for Jack Mackerel and Mackerel, Supreme Decree N° 011-2007-PRODUCE.

### 6.1 Fisheries management measures for Jack mackerel in 2013

The various fisheries regulations issued by the Ministry of Production in 2013 include:

R.M. N° 038-2013-PRODUCE, January 18, 2013. Authorized the Peruvian Institute of Marine Research (Instituto del Mar del Perú, IMARPE) to conduct an exploratory fishing operation for Jack mackerel and mackerel in the Peruvian jurisdictional waters, with commercial vessels, until February 10, 2013.

R.M. N° 077-2013-PRODUCE, February 18, 2013. Setting a total allowable catch (TAC) for Jack mackerel of 80 thousand tons to be caught by the industrial fleet in two periods, with 40 thousand tons each. The first period was set from February 20 to March 19 and the second from March 20 to April 15 of 2013. It was established that the fishery would have been closed upon completion of the TAC or at the end of the established period.

R.M. N° 161-2013-PRODUCE, May 3, 2013. Extended the fishing period for Jack mackerel to May 4-16 taking into account that the TAC was not reached. The catch volume not taken by the fleet was of 64 996 tons.

R.M. N° 285-2013-PRODUCE, September 14, 2013. Extends the fishing period from September 16 to December 31, 2013, in order to let the fleet catch the remaining (53 104 tons) of the TAC authorized earlier by R.M. N° 077-2013-PRODUCE.

The 2013 fishery for Jack mackerel (*Trachurus murphyi*) in the Peruvian national jurisdictional waters are being regulated under the Peruvian national Legislation within the framework of the Fisheries Management Regulation of this species. By September 14, 2013 the total catch of Jack mackerel by the industrial fleet was 26 896 tons, that is only the 33.6% of the total allowable catch set up at the beginning of the year for the industrial fleet.

## 7. ADVANCES IN JACK MACKEREL STOCK ASSESSMENT RESEARCH

The Peruvian Institute of Marine Research (IMARPE) has an active research programme that continuously looks into the different aspects of the marine environment, the fishery and the biology and ecology of Jack mackerel and other commercially important species. A good part of this work devoted to Jack mackerel is yielding interesting and valuable results that have direct applications in the improved assessment and management of the stock. Several of this works are now coming to light through a selection of 13 articles being published under a single special issue of a well recognized Peruvian Journal devoted exclusively to the Peruvian Jack mackerel (Csirke *et al* 2013). Observations, data and findings reported in this recent publication are providing significant working material and motivation for the further development and application of stock assessment models and methods to tackle specific stock assessment problems and sources of uncertainty in Peru, and possibly elsewhere in the south Pacific.

One major problem identified in the assessments of the Peruvian Jack mackerel stock is the low reliability and poor coverage of the acoustic biomass estimates being made through regular acoustic surveys by IMARPE, and this has motivated a novel and potentially very valuable line of research aimed at standardizing past and future acoustic biomass estimates of Jack mackerel in Peru based on the accumulated knowledge on its biology and environmental preferences and constrains. Given its relevance for the present and future assessments of Jack mackerel in Peru and in the region, a brief account of this novel approach is provided here. For the time being this index is based on an abiotic dimension of the potential habitat of Jack mackerel while a more comprehensive approach shall be underway soon.

### 7.1 Standardization of the Peruvian acoustic index

The Peruvian acoustic surveys are traditionally directed to the assessment of anchoveta and are designed to cover fully its entire distribution. Therefore, and due to time and cost constrains the areas surveyed cover the whole coastline but are limited to the more coastal areas from 0 to 80 and eventually 100 miles from the coast. This usually covers only part and usually a variable portion of the whole distribution area of Peruvian Jack

mackerel. For this reason there is a non-systematic bias in the area covered for Jack mackerel and a procedure is being devised to standardize the acoustic biomass estimates by an environmental index describing the potential habitat of Jack mackerel.

### 7.1.1 Material and methods

#### 7.1.1.1 Data

Georeferenced estimates of presence and absence for Jack mackerel were obtained from three sources: i) hydroacoustic surveys conducted by IMARPE; ii) logbooks from observers onboard part of the industrial purse seine fleet; and, iii) catch reports including Jack mackerel fishing sites from the artisanal (indirect position estimated) and the industrial (taken from satelite positioning system) fleets. Monthly data from 1985 to-date was selected. Pseudo-absences were generated in the South Pacific gyre (0-25°S, 90-100°W) and the Equatorial zone (5-10°N, 85-100°W), in order to balance the proportion of presences and absences.

The selected environmental variables (Espino 2013, Flores *et al* 2013) were Sea Surface Temperature (SST), Sea Surface Salinity (SSS), water masses (WM), oxycline depth (OD) and chlorophyll (CHL). The chlorophyll is used as a proxy of food for Jack mackerel (zooplankton). These variables were obtained from in situ and remote sensing databases (SST: Pathfinder and MODIS, SSS: SODA with data assimilation, CHL: SeaWIFS and MODIS) and ROMS-PISCES model (OD).

#### 7.1.1.2 Estimating the potential habitat of Jack mackerel

A GAM model was built to model the relationship of presence and absence of Jack mackerel to five environmental variables (SST, SSS, WM, OD, CHL). A logit link function was used so the probability P of presence of jack mackerel was:

$$P = Logit(PA_{jurel}) = f(SST, SSS, WM, OD, CHL)$$

To predict areas with presence of Jack mackerel a cut-off point ($\lambda_{ROC}$) was calculated as the value maximizing the area under ROC (Receiver Operating Characteristic) curve (AUC). The probability P was then expressed as a function of latitude (x), longitude (y) and time (t).

$$P(x, y, t) = f(SST(x, y, t), SSS(x, y, t), WM(x, y, t), OD(x, y, t), CHL(x, y, t))$$

Based on these predictions the area of the potential habitat for Jack mackerel ($A_P$) was calculated as the total area with a probability of presence greater than the threshold value $\lambda_{ROC}$. The area of the potential habitat covered by the survey ($A_S$) was also calculated. It was assumed that jack mackerel density is proportional to the probability of occurrence inside the area of the potential habitat $A_P$, defining the standardized acoustic index as:

$$I_e(t) = I(t)\frac{\int_{A_P} P(x,y,t)\,dx\,dy}{\int_{A_S} P(x,y,t)\,dx\,dy},$$

Finally, the potential habitat index ($H_P$) was defined as

$$H_P(t) = \int_{A_P} P(x, y, t)\, dx\, dy$$

### 7.1.2 Results

The smoothed linear predictors for the GAM model are presented in Figure 21. The area under the ROC curve (AUC) was 0.9646, indicating a very good quality of the classification model for presences and absences. The threshold of $\lambda_{ROC}$ was calculated in 0.49 (Figure 18, lower right panel).

The potential habitat index ($H_P$) from 1985 to 2013 is shown in Figure 22 and the standardized index $I_e$ used for the 2013 assessment in section 5.2 above is shown in Figure 23.

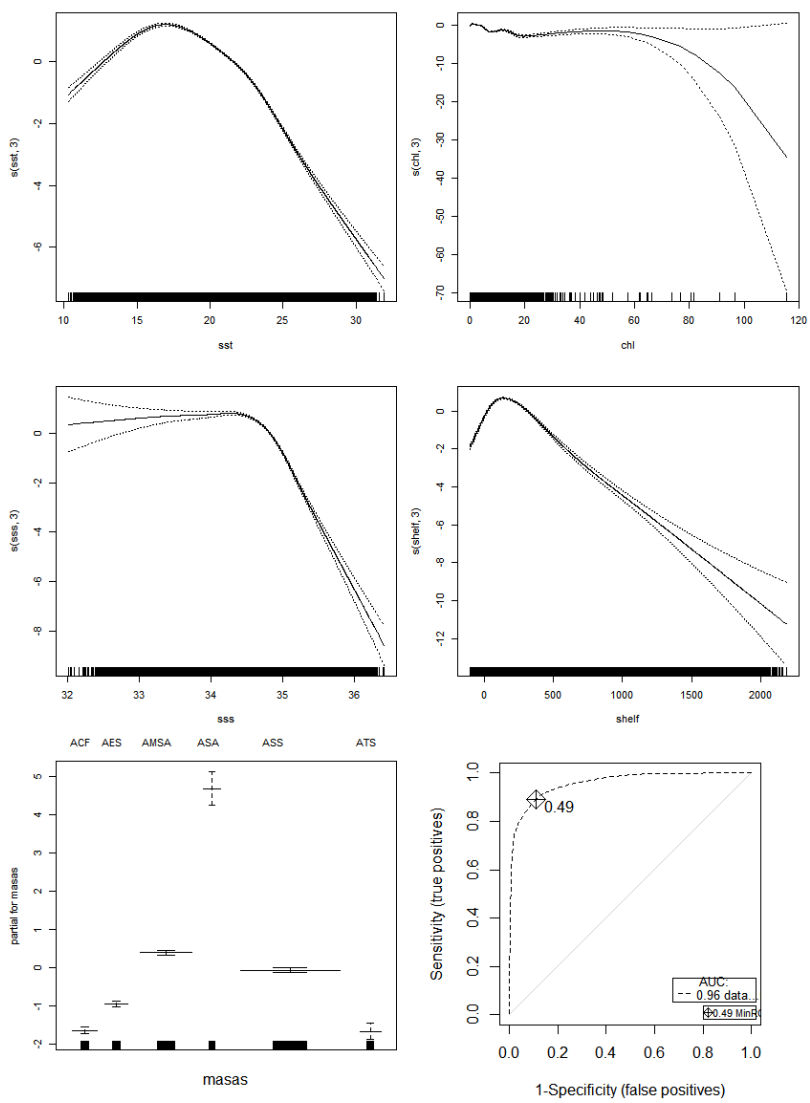


**Figure 21. Non-linear predictors for the GAM model and ROC plot (right bottom) for the Peruvian Jack mackerel potential habitat model.**

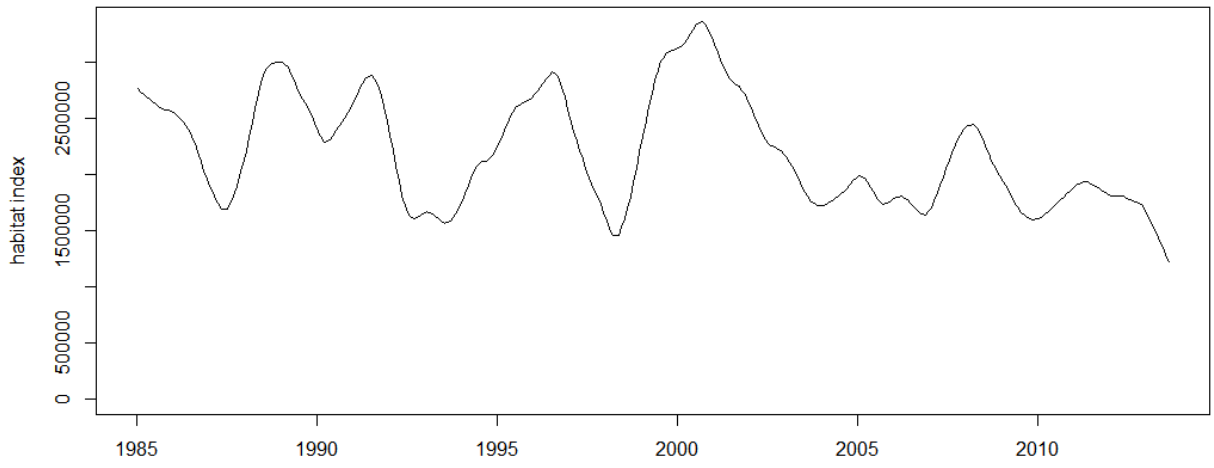


**Figure 22. Potential habitat index ($H_P$) for Peruvian Jack mackerel stock (far-north stock).**

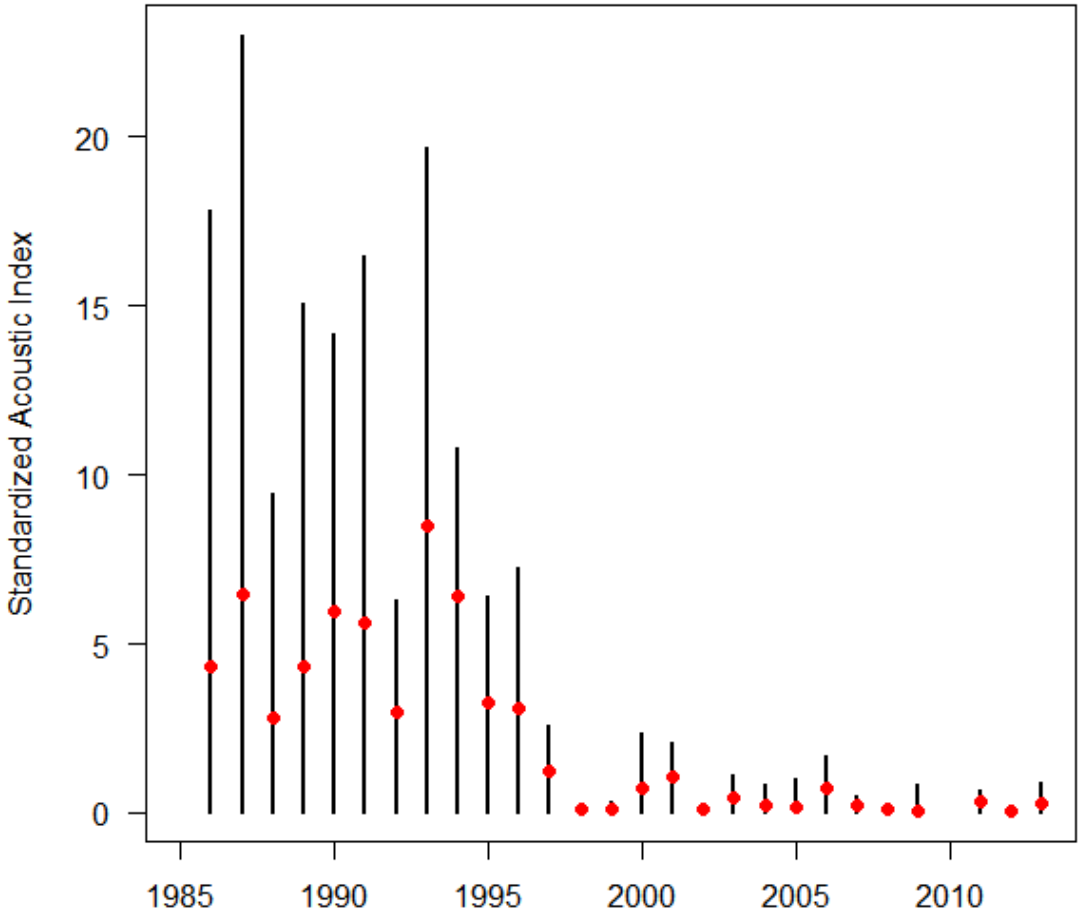


**Figure 23. Acoustic index (dots) and standardized acoustic index (thin vertical bars) for the Peruvian Jack mackerel stock (far-north stock).**

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