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NATIONAL REPORT ON THE SITUATION OF THE PERUVIAN STOCK OF JACK MACKEREL (NORTHERN STOCK) AND THE PERUVIAN FISHERY IN NATIONAL JURISDICTIONAL WATERS

2012

NATIONAL REPORT No. 2
SITUATION OF THE PERUVIAN STOCK OF JACK MACKEREL (NORTHERN STOCK) AND THE PERUVIAN FISHERY IN NATIONAL JURISDICTIONAL WATERS

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1. INTRODUCTION

Large environmental variations are known to cause also large year-to-year fluctuations as well as longer-term changes in fish abundance and total production of the main exploited species in the Southeast Pacific, including the jack mackerel (Jordan, 1983; Zuta, Tsukayama and Villanueva, 1983; Serra, 1983, 1991; Csirke, 1995).

Historical records show that there has always been a wide distribution of jack mackerel (*Trachurus murphyi*) at least in the coastal areas off Peru and Chile, although there is no evidence of this species being in particularly high abundance (as in the 1970s-1990s) prior to 1970. However, in the early 1970s jack mackerel started to appear consistently as by-catch in local artisanal and industrial fisheries, and in the mid-1970s and 1980s more specialized Chilean, Peruvian and the ex-Soviet Union fishing fleets began targeting on this species. This caused the rapid increase in total catches of jack mackerel from the Southeast and the Southern-central Pacific that peaked at almost 5 million tons in 1995.

The wide distribution of jack mackerel in the South Pacific, the noticeable changes in the extent of its main concentration areas and the associated high variability in abundance - most likely caused by large scale environmental fluctuations in the South Pacific, particularly in the Southeast Pacific - has made it difficult to establish distinguishable stock units for the jack mackerel in the area. The possible existence of two or more subpopulations of this species was proposed in the early 1990s by Serra (1991) and by Arcos and Grechina (1994). The available evidence and most likely hypothesis about the stock structure of the jack mackerel in the South Pacific were then reviewed and discussed in 2008 in the context of the South Pacific Regional Fisheries Management Organization (SPRFMO), and one of the main hypothesis (Hypothesis No. 1) being considered as the most viable was that *"jack mackerel caught off the coasts of Peru and Chile each constitute separate stocks which straddle the high seas".* It was then also agreed that there was a fairly substantial amount of historic and current evidence supporting this hypothesis, although it was recognized that there were still uncertainties regarding the most likely separation area between these Peruvian and Chilean stocks. In this respect we note that there are some indications that the most likely separation of the Peruvian stock (or northern stock) from the more southern stock(s) would be somewhere around the “Subtropical Convergence”. This issue is further discussed in another document being presented for consideration in this same SWG meeting.

Some recent analyses by Gerlotto *et al.,* (2010 and 2012) suggest that the stock structure of the jack mackerel in the South Pacific might be best described as a metapopulation, with a source population contributing to several subpopulations or stocks that can remain separate for long periods or have periods of certain degree of intermixing, depending on environmental conditions. This proposal is not entirely incompatible with Hypothesis 1 mentioned above and being assumed as the main working hypothesis for the analyses in this report.

2. THE MARINE ENVIRONMENT

One of the world main marine zones with the highest biological productivity is located off the occidental coast of South America, and this increased productivity has a noticeable impact on all the trophic levels of the marine ecosystems in the area. The coastal 200 miles jurisdictional waters off 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 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 upwelling carrying to the surface deep and cold water masses, rich in nutrients (Zuta and Guillén, 1970; Pocklington, 1981).

2.1 Main current systems and water masses

It is because of these processes that the Peruvian sea has typically temperate to cold waters even if located at low latitudes that correspond to a tropical climate. Even if being in the tropic, temperate - cold conditions prevail in the area, but nevertheless this is eventually interrupted by the El Niño events which cause a temporal prevalence of tropical climate in the system, reminding us at which low latitudes we are (Margalef, 1974).

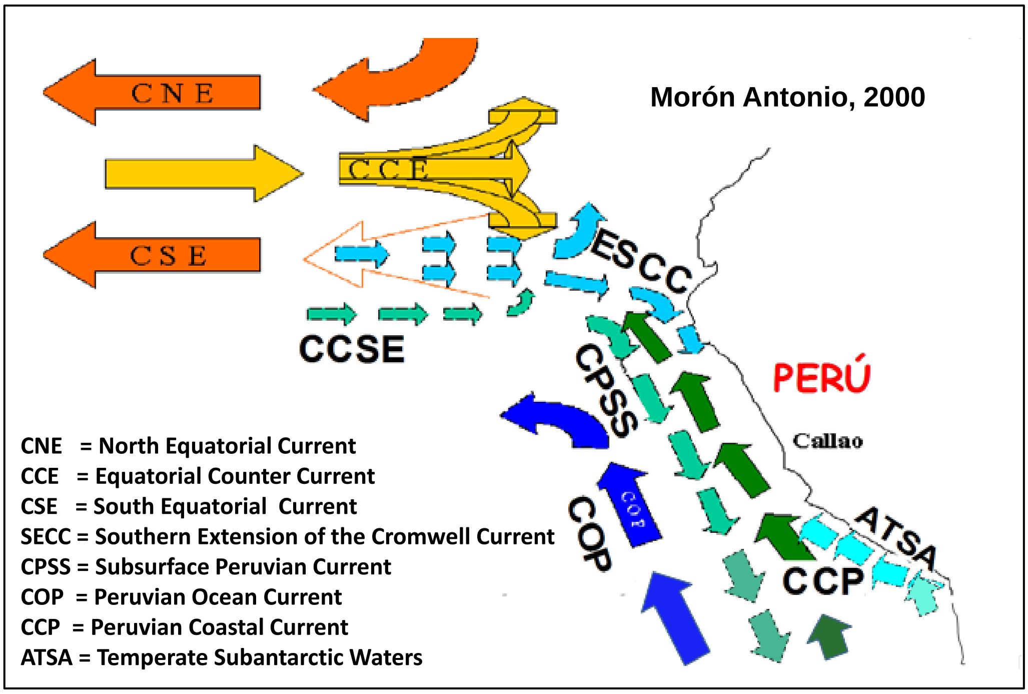

Figure 1. Currents and Undercurrents in the Peruvian Sea

A complex system of surface and subsurface currents flows along the Peruvian coast (Fig. 1). In this context, the different environmental scenarios in the Peruvian sea can be briefly described as follows:

a) An extended area of coastal upwelling dominated by the Cold Coastal Waters (CCW) that normally spreads from 0 to 60 miles from the coast and may extend to as far as 100 miles offshore depending on the season and the phase of Pacific Decadal Oscillation (PDO). In general, during a positive PDO phase there is a weakening in the coastal upwelling, while during a negative PDO phase (as at present) there is a strengthening of the upwelling. During positive a PDO phase an upwelling of equatorial origin will be dominant, mainly fueled by waters from the Southern Extension of the Subsurface Cromwell Countercurrent (SESCC). While during a negative PDO phase, coastal upwellings are mainly fueled by the Intermediate Sub-Antarctic Waters, which from the south can extend as far north as the 06ºS;
b) Periods of negative phase of PDO (as in the 1950s to mid-1970s and the 2000s to present) are typically lower in biodiversity but much higher in total biomass, mainly dominated by anchoveta (*Engraulis ringens)*, while positive PDO phases (as in the mid-1970s to 1990s) are of higher biodiversity with dominance of sardine *(Sardinops sagax sagax)* as well as jack mackerel (*Trachurus murphyi*), mackerel (*Scommber japonicus peruanus*) and other species. The alternation between anchoveta and sardine can be explained by this medium to long term environmental fluctuations (Chavez, *et al* ., 2003);
c) A reduced area influenced by Surface Tropical Waters north of 04º S, with very high biodiversity but low biomasses;
d) The mixing zone, between 04°S and 06ºS, with an alternating influence from the above mentioned water masses from the south or from the north, depending of the dominant season of the year. During winter the more southern conditions prevail while during summer the northern conditions prevail. This zone is also characterized by a high biodiversity, although less than in (c) above, as well as also low biomass;
e) The oceanic area adjacent to the coastal upwelling zones is dominated by the warm and high salinity Surface Subtropical Waters (SSW). This water mass becomes more intense and remains nearer to shore during the austral summer and fall, and becomes weaker and moves farther offshore during winter and spring. The oceanic front, that is where the

encounter between CCW and SSW occurs, forms a mixed layer water column from the surface to more than 1000 meters deep. This mixed water column is dominated by the mesopelagic lantern fish (*Vinciguerria lucetia pacifici*), which is the main prey for tunas, common dolphinfish, jumbo squids and mainly jack mackerel. In fact, during some of the recent years, the highest concentrations of "vinciguerria" were found off southern Peru, where high catches of jack mackerel were also taken (Gutierrez, 2002);

f) In the north, two sub-surface current subsystems can be identified. One formed by the Southern Extension of the Sub-superficial Cromwell Countercurrent (SESCC) associated with the continental shelf and the presence of hake (*Merluccius gayi peruanus*), and the Sub-surface Peruvian Current (SSPC) that is more oceanic, can extend as far south as 40ºS and is associated with the presence of jack mackerel (*Trachurus murphyi*); and the other subsystem formed from the south by the Sub-Antarctic Temperate Waters, associated with the presence of toothfish (*Dissostichus eleginoides)* and related fauna; and,

g) The near shore systems with coastal rocky and sandy environments dominated by coastal fishes, mollusks, crustaceans and echinoderms of high economic value that support important local artisanal fisheries..

2.2 Variability patterns

The area is characterized by the variability of environmental conditions that respond to changing patterns at different time scales. These patterns, which can range from seasonal to secular, can be identified and eventually be monitored through the temporal changes in various environmental variables and indexes such as sea surface temperature (SST), the Pacific decadal oscillation (PDO) index, the multivariate ENSO index and the Southern Oscillation Index (SOI), amongst others. The analysis of these indicators allows the identification of seasonal (summer-winter), inter-annual (El Niño-La Niña), inter-decadal (warm and cold multiyear periods (Chavez, *et al*, 2003), and secular (Espino, 2003) scale patters. From all these variable scale patterns, the most relevant in trying to explain the changes in availability of jack mackerel during the last 30 years are the inter-annual processes that correspond to the dynamic of El Niño Southern Oscillation (ENSO) and the multiyear longer term ones, better known as inter-decadal.

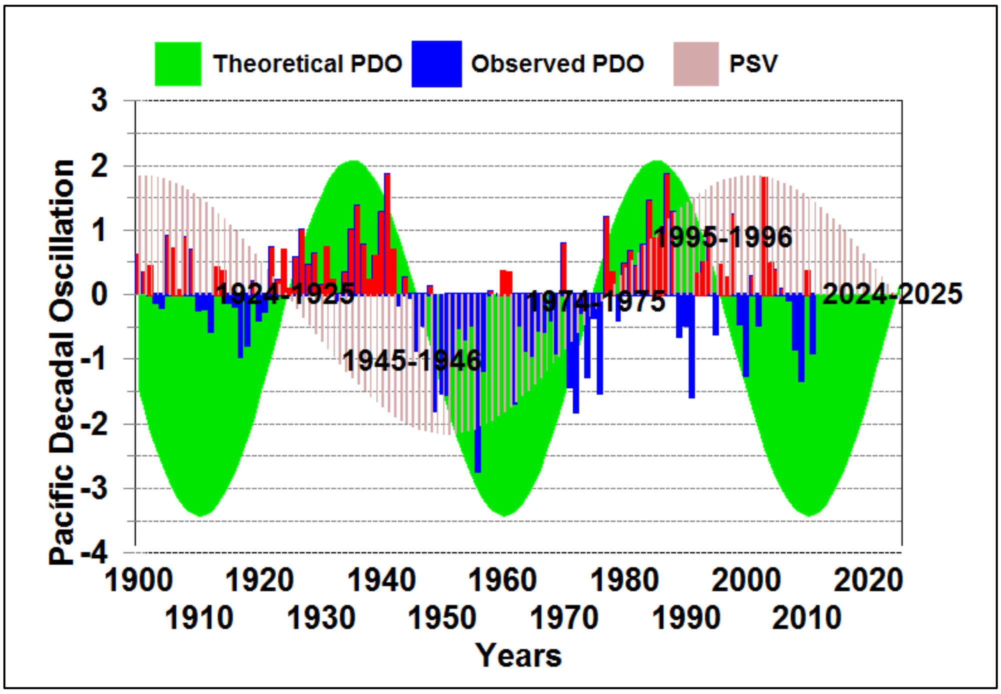

Figure 2. Pacific Decadal Oscillation and Pacific Secular Variability (Espino, 2003)

Inter-annual processes associated with ENSO affect the distribution and abundance patterns of fish stocks such as the jack mackerel, and therefore its local abundance and availability to the fishery. While inter-decadal processes, with periods of 20-30 years, affect the structure of the ecosystem with more profound and longer-lasting effects on the abundance of the fish stock(s) and the development of their fisheries. These longer pattern changes are also known as regime shifts, as they may cause noticeable and long lasting changes in the ecosystems, the fish populations and the organization of the fisheries systems of the countries involved (Schwartzlose *et al*, 1999; Hare, 2002; Chávez *et al* , 2003; Alheit and Ñiquen, 2004; Hsieh *et al* , 2005). Thus, these longer term variability patterns may affect and modulate the effects and severity of the shorter term ENSO patterns (Fig. 2) (Espino, 2003; Wang and Picaut, 2004; Wang *et al* , 2004; Cobb *et al* , 2004; Wang and Fiedler, 2006).

There are numerous evidences of the occurrence of these variability patterns in the past and there are records on some of them, such as on the ENSO dated as far back as 400 000 years ago (Mid-Pleistocene) (*Guzmán et al .,* 2001; *De Vries et al . 1997*; Sandweiss *et al .* 1996; Pierrer *et al* ., 1994; Andrus *et al* ., 2005; De Vries *et al .* 1997; *Pierrer et al . 1994 y Andrus et al . 2005;* Wells, 1990; Smith, 1992; Rodbell *et al .* 1999; Riedinger *et al* . 2002; Simeone & Navarro, 2002; Hebbeln *et al* ., 2002; Sandweiss, 2003).

More recent observations also provide confirmation of local expressions of decadal variability patterns, as can be seen from the sea surface temperature records and the sea surface temperature anomalies since 1925 in the port of Chicama (07°41'S) (Fig. 3).

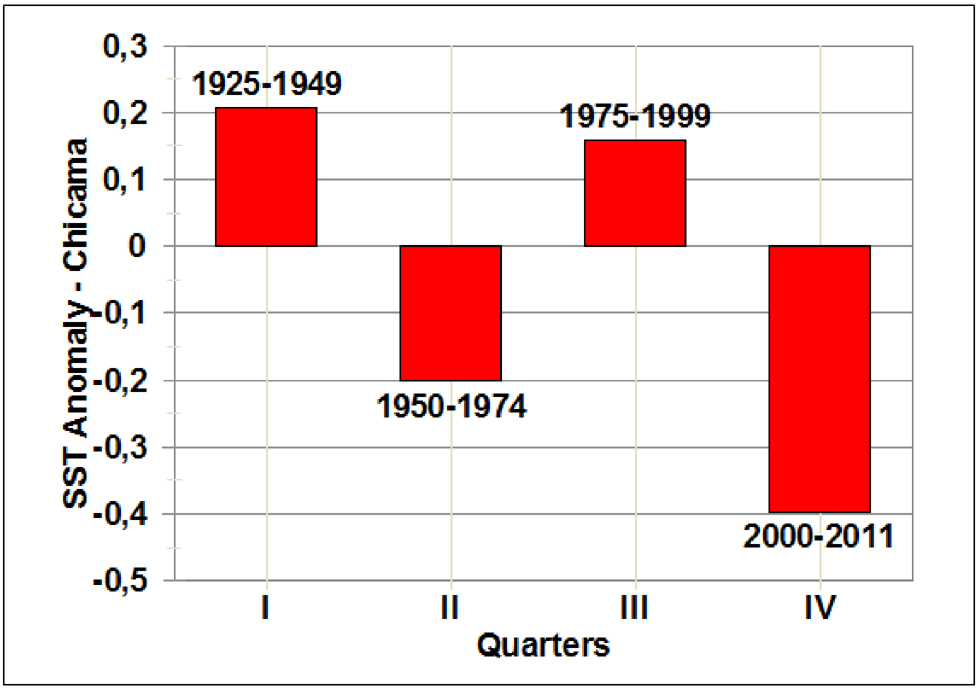

Figure 3. Sea Surface Temperature Anomaly (SSTA) by quarters in Chicama-Perú

Another decadal pattern can be observed from the analysis of the changes in the 15ºC isotherm depth between 1961 and 2011 off Peru (Fig. 4A). There is a clear deepening of this variable during the decades of the 1980s and 1990s, which is an indicator of favorable sub-surface conditions for the presence and expansion of fish stocks such as hake and jack mackerel, associated with equatorial currents such the Southern Extension of the Sub-superficial

Cromwell Countercurrent (SESCC) and the Peruvian Subsurface Current (PSSC).

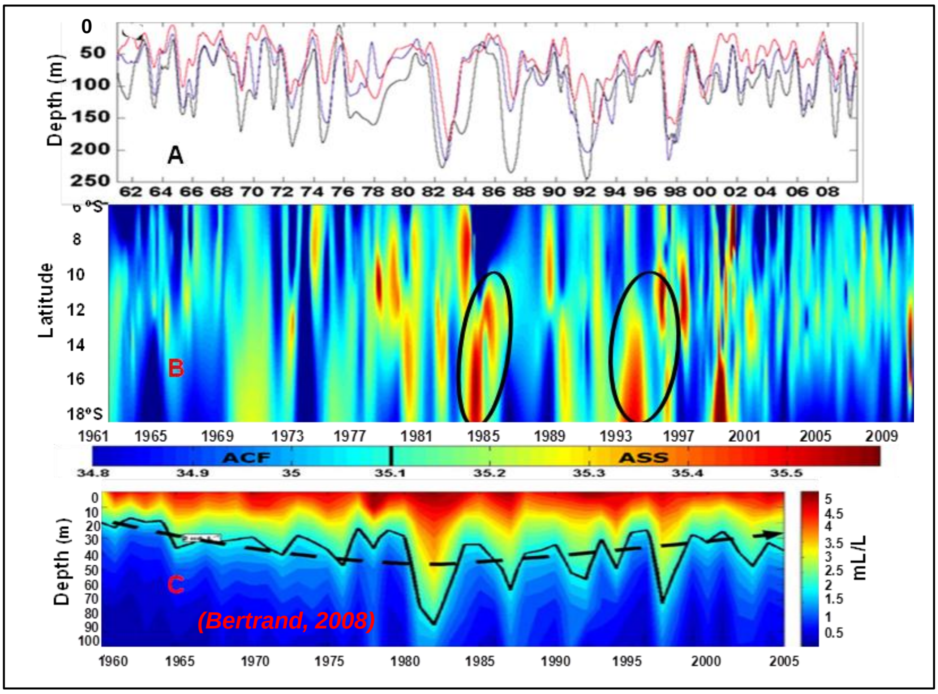

Figure 4. Depth (m) of the isoterm of 15º C (A); Spatial distribution of salinity between 05º to 18º S and from 50 to 100 nm offshore (B); and depth (m) of the oxygen minimum line (C).

For the same time period the spatial distribution of salinity (Fig. 4B) and of the depth of the oxygen minimum (Fig. 4C) shows that toward the end of the 1970s and during the1980s and 1990s the prevailing conditions were those determined by the intrusion of Superficial Subtropical Waters (SSW), with water masses with temperatures ranging between 15°C and 20ºC, salinities between 35.1 ups and 35.6 ups and oxygen content between 1.0 and 6.0 mL/L, which are the preferred environmental conditions reported for the jack mackerel off Peru.

The available evidence suggests that these environmental patterns and processes may have been prompting an adaptation process in the life history and population dynamics of several fish stocks such as the jack mackerel off Peru. Presumably causing adaptations which in the very long term may lead to changes in the genetic pool, particularly if the differentiating environmental signals are persistent enough and the isolation of the subject group or stock lasts long enough. This may not be precisely the case of the jack mackerel, where at least some occasional flow from one group or stock to another may occur at periods of particularly high abundance and population bloom, and/or when severe occasional perturbations of the marine environment occur ‘resetting’ the system (Bakun and Weeks, 2006). Nevertheless, and even if there are no conclusive genetic studies to prove it, there is abundant evidence supporting of a stock differentiation, expressed through differences in several some important life-cycle traits and population dynamics characteristics.

3. CHARACTERIZATION OF THE STOCK

3.1 Distribution patterns

3.1.1 Observations from fishing operations

Apparently the jack mackerel has always had a wide and at least scattered distribution along the Peruvian coast. In fact, early historical fishery records from 1907 show that the jack mackerel had a wide distribution along the whole Peruvian coast, with presence from Paita (05ºS) to Mollendo (17ºS), (Coker,1908 & 1910). .

Starting in 1972, jack mackerel expanded its distribution with frequent high concentrations along the coast, especially after El Niño 1972. During El Niño years in 1972 and 1976 the distribution areas as well as the areas with dense concentrations of jack mackerel increased and became larger than those previously observed. The trends of the isolines of high seasonal aggregations of jack mackerel as calculated form the catch data of the Peruvian purse seine fleet from 1972 to 1983, suggest a displacement of these concentrations towards the southern part of the Peruvian coast (Fig. 5), with an increased incidence of large concentrations (orange to red in Figure 5) south of the 10°S from 1976 to 1979 and during El Niño 1982-83 (Zuta *et al* .,1983).

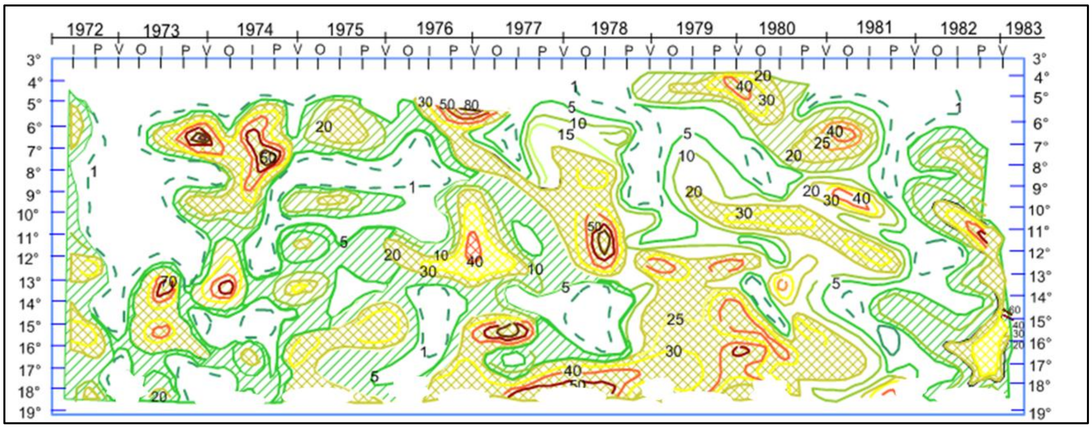

Figure 5. Seasonal and interannual variations in the distributions and "indexes of agregations" of Jack Mackerel in the Peruvian Sea. Winter 1972-Summer 1983 (Zuta et al., 1983)

Data from fishing activities of the ex-Soviet Union trawl fleet that operated in Peruvian waters in 1983-1985 and 1989-1991 (Fig. 6) shows that the areas of large concentration were found mainly in the north and central part. This suggest a northern shift of the areas of higher concentration during 1982-1983 (El Niño year) and the much cooler conditions in 1984.

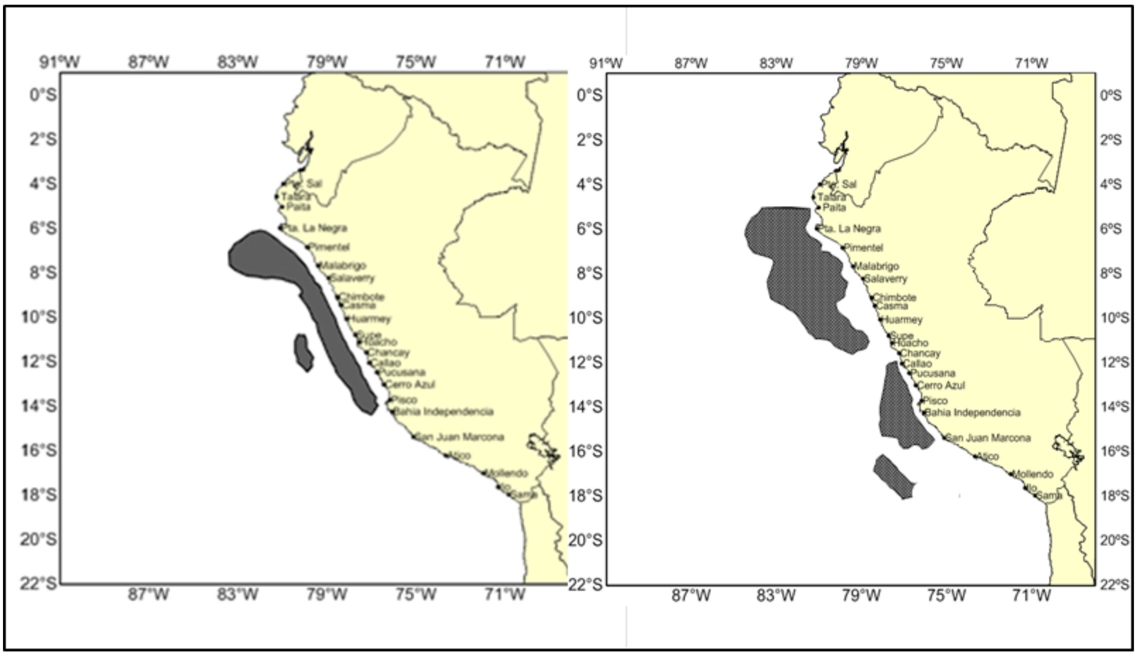

Figure 6. Fishing areas of the ex-Soviet trawl fleet in Peruvian sea

Analyzing data from the same fleet, Icochea *et al* . (1998) described a very coastal distribution during 1983 (an El Niño year) with a wide distribution, reaching as far as 150 miles offshore during the cooler conditions of December 1984 (Fig. 7). Data from this same fleet shows that the vertical distribution of jack mackerel has had significant variations between 1983 and 1984 (Fig. 8), with vertical movements from the surface to depths of 350 m (Dioses and Ñiquen, 1988).

Under normal conditions schools of jack mackerel are found at depths below 10 to 100 m, while under colder conditions (as in 1984) schools are shallower while in warm conditions (as in 1983) schools may be found even below 100 meters.

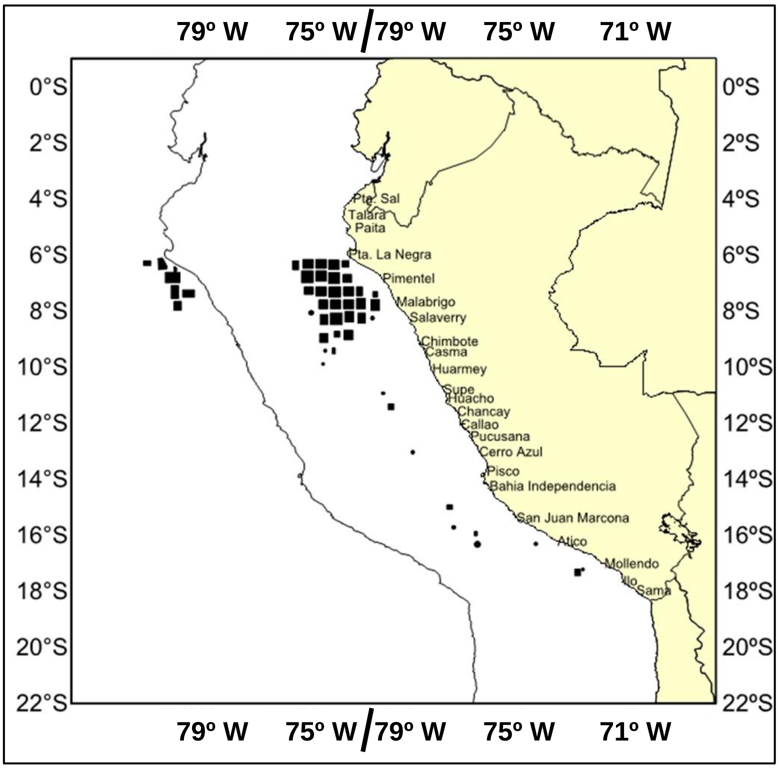

Figure 7. Fishing areas of the Soviet trawler fleet in peruvian jurisdictional waters in 1983 (A) and 1984 (B) (Icochea, 1988)

Catch records by region from 1990-2011 (Table 1) show the latitudinal changes during these years suggesting a shift from north to south around 2001-2002 (Espinoza *et al*, 2008). These two scenarios can be seen more clearly in Fig. 9. Between 1996 and 2001 most of the fleet operated in the northern-central region (03º30'S – 14ºS), while between 2002 and 2011 the catches of jack mackerel were mostly in the central and southern region (11ºS – 18ºS), except for 2006 and 2012 (the observations for 2012 are still incomplete), when the fleet also operated in the north. Longitudinally, the fishing activities took place from very close to the coast to as far as 200 nm offshore, with a more coastal distribution during warm periods. The same figure also shows the presence and distribution of juveniles throughout the whole period (red circles) following more or less the same distribution of adults (blue dots).

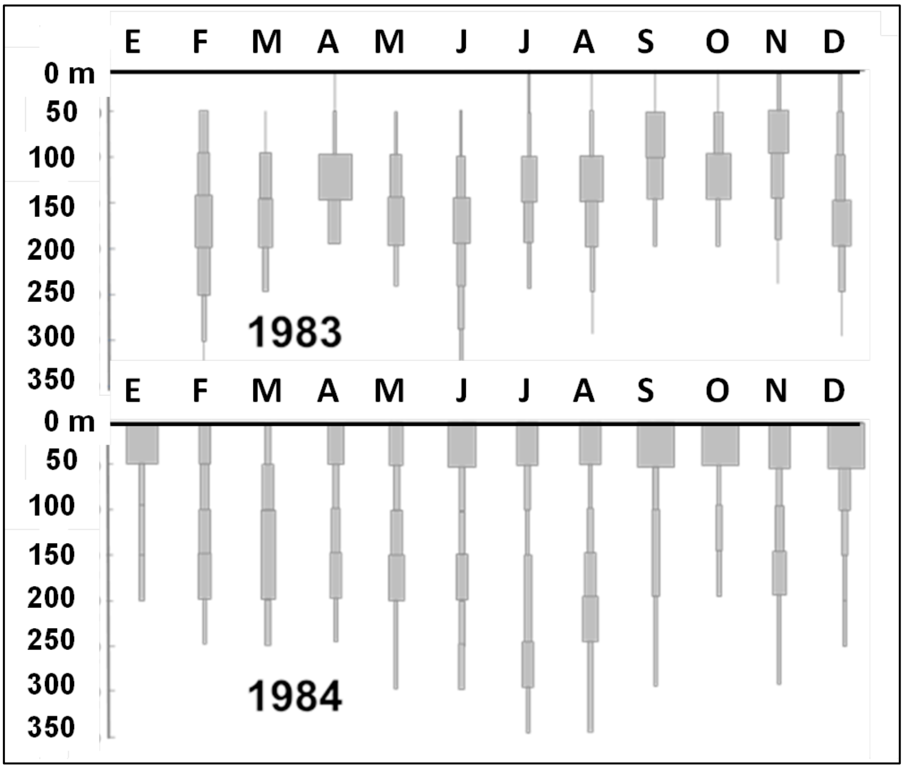

Figure 8. Monthly vertical distribution of Jack mackerel from 1983 to 1984 (Icochea, 1988)

Table 1. Jack mackerel purse seine catches by regions during 1990-2011 (in tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
NORTH	181.908	127.837	88.449	118.110	190.013	365.767	273.515	629.509	368.191	173.888	257.715
CENTER	7.528	7.808	4.298	3.480	5.899	9.164	129.817	19.093	6.840	8.238	34.139
SOUTH	1.704	692	3.914	9.091	859	1.669	35.404	1.149	11.914	2.553	4.724
TOTAL	191.139	136.337	96.660	130.681	196.771	376.600	438.736	649.751	386.946	184.679	296.579

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
NORTH	258.812	1.022	385	-	1.175	64.618	7.134	90	100	270	101.308
CENTER	433.446	122.803	92.668	151.452	27.683	189.790	178.397	70.322	25.312	30	155.761
SOUTH	31.475	30.394	124.683	35.916	51.806	23.160	68.895	99.125	500	-	172
TOTAL	723.733	154.219	217.735	187.368	80.663	277.568	254.426	169.537	25.912	300	257.241

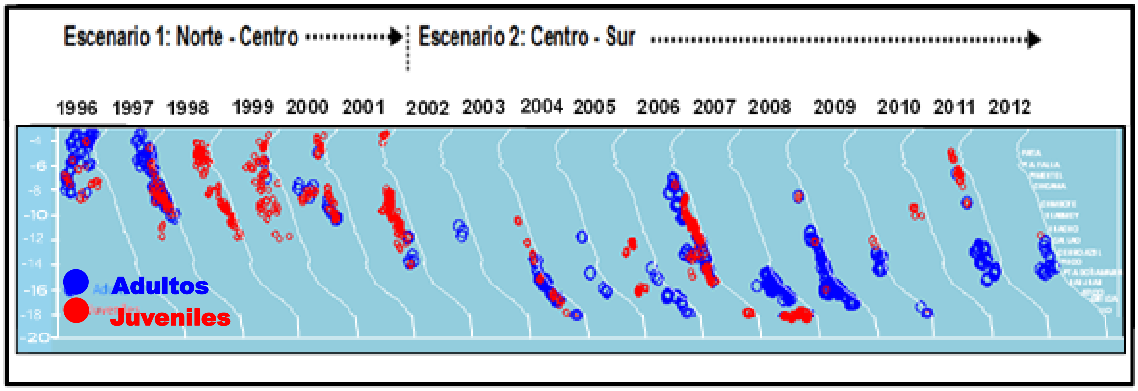

Figure 9. Distribution of the Jack mackerel catches sampled on board during the fishing activities of the purse seiners fleet from 1966 to 2012

The analysis of the latitudinal distribution of fishing sites (see Fig. 10 showing the mean latitude ofcthe fishing sites by year weighted by the catch) also confirm the above observation regarding the displacement of fishing zones from north to south with the break-point in 2001-2002 (Espinoza, 2008).

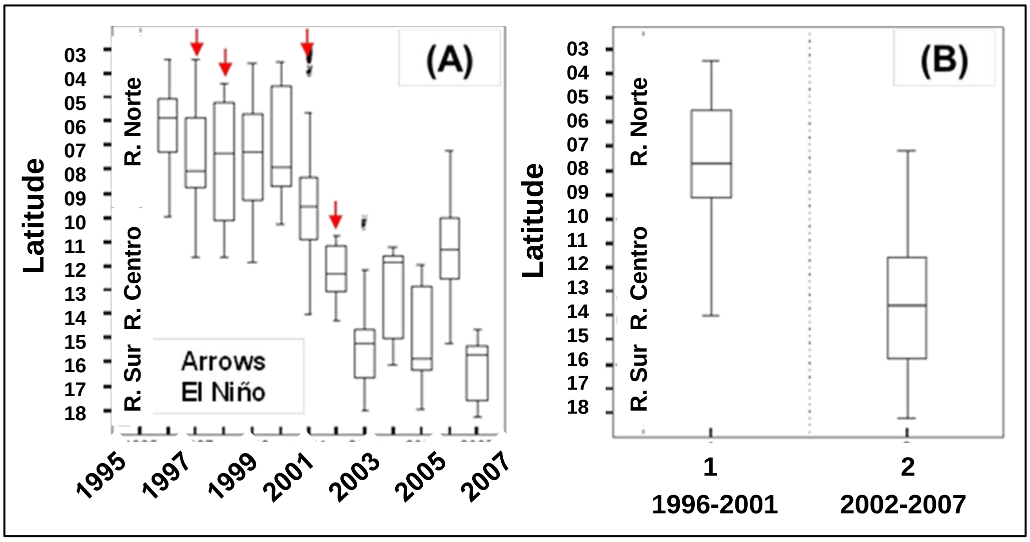

Figure 10. (A) Annual variation of the weighted mean latitude of the fishing areas of jack mackerel from 1996 to 2007 (red arrows indicate El Niño events) and (B) weighted mean latitude for two periods

The distance from the coast of the fishing areas during the period 1996- 2007 show an important variability (Fig. 11A). With the year 2001 as the break-point, it is clear that before that year the fishing zones were farther than 50-60 miles from the coast, while after 2001 these were predominantly within the first 60 miles except for 2006. On this it is worth noting that when comparing the distance from the coast with latitude along time, before 2001 the fleet operated in the northern-central region (lower latitudes) and farther than 60 nm offshore, while after 2001 the fleet operated in the central–southern region (higher latitudes) and closer to the coast (Fig. 11B) and this inshore contraction of the fishing zones is somehow related to the amplitude of continental shelf, which is wider in the north and becomes narrower in the south.

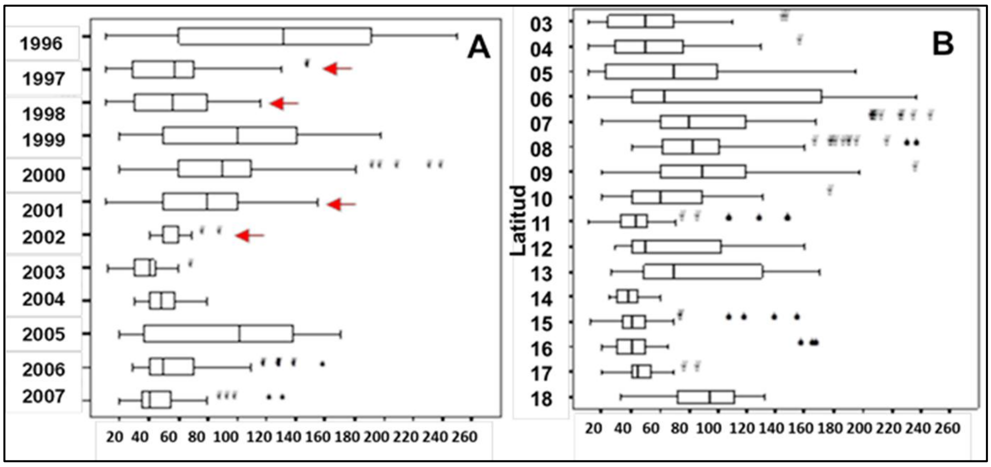

Figure 11. (A) Annual mean distance from de coast of the jack mackerel catches from 1996 to 2007 (red arrows indicate El Niño events) and (B) mean distance of the catches by latitude in the same period.

3.1.2 Observations from acoustic surveys

Changes in jack mackerel distribution patterns can also be observed from the results of the acoustic stock assessment surveys conducted by IMARPE since 1983. Although these cruises were mainly targeting on anchoveta which is a neritic species found closer inshore, mostly within the first 80-100 from the coast, the data collected still provides valuable and reliable information on the distribution and availability of jack mackerel within the neritic part of its total distribution.

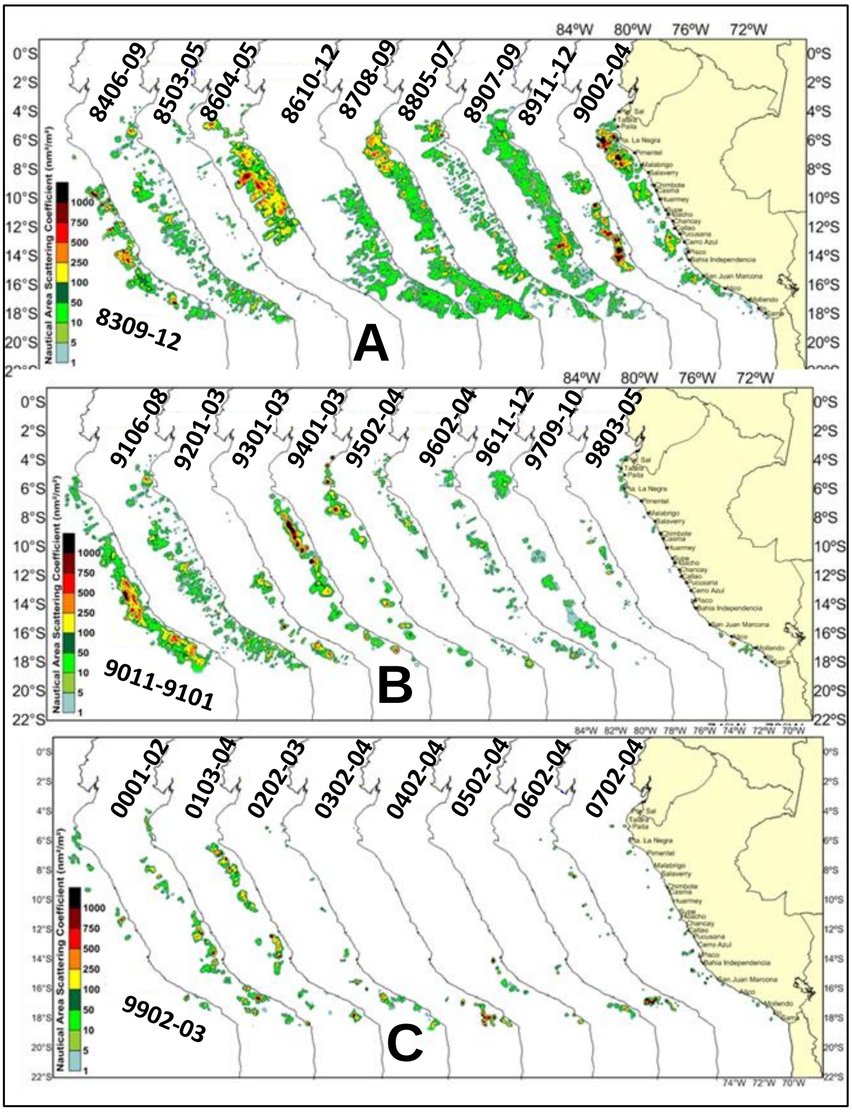

Figure 12. Distribution and abundance of jack mackerel off Peru, as obtained from acoustic stock assessment surveys, 1983 to 2007

During 1983-1990 the neritic distribution of jack mackerel was almost continuous in the whole surveyed area (Fig. 12A), with the highest density concentrations principally north of Pisco (14°S). Between 1990 and 1998 the distribution areas also extended along the coast, but were getting smaller and with low densities, particularly after 1996 (Fig. 12B). Between 2000 and 2007 (Fig. 12C) the distribution was more disperse than in previous years, with scarce and low-density nuclei along the coast and with some years when distribution was mainly south of Pisco (14°C) (Ganoza, 1998; Castillo *et al*, 1999).

In the more recent years the distribution and abundance patterns observed through the acoustic stock assessment surveys have followed a general trend similar to previous years, although the results from the fishery have been significantly different. These differences may partly be explained by the fact that part of the fleet tended to operate farther offshore, outside the areas surveyed by the acoustic cruises.

3.2 Acoustic biomass estimates

Although the surveyed area has not covered the whole area of distribution of jack mackerel, the biomass estimates of these acoustic stock assessment surveys since 1983 are valuable pieces of information to help in building the jack mackerel puzzle. These estimates must be considered not as total biomass of the whole stock, but as an index of its availability within the neritic zone of the Peruvian coast.

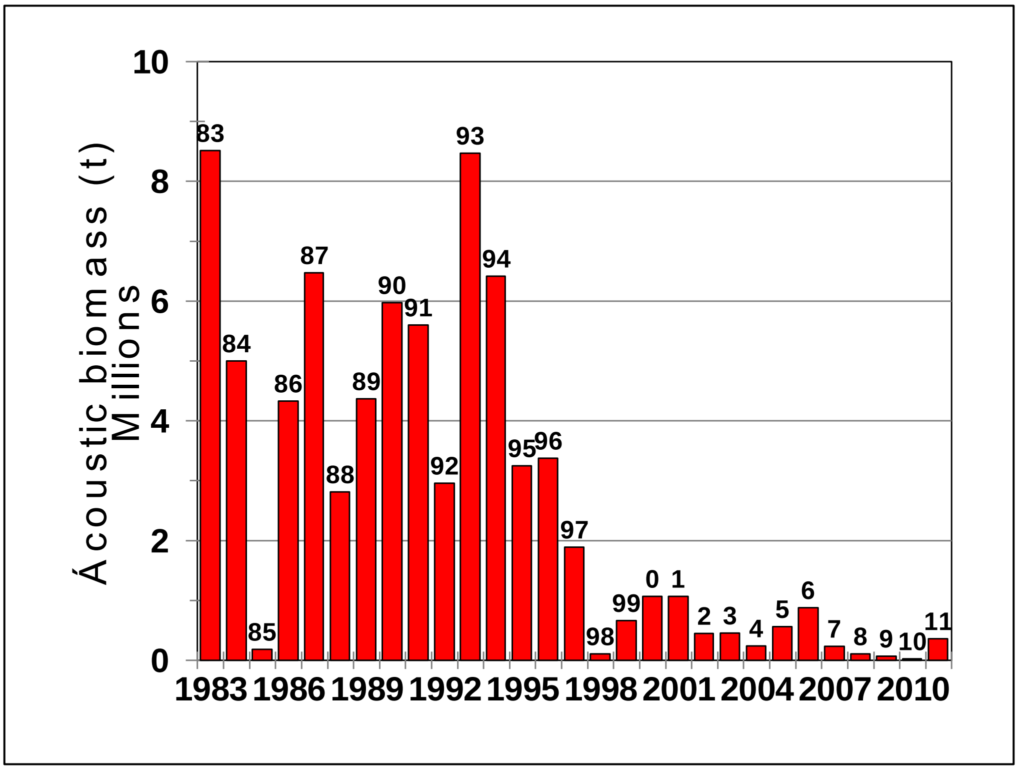

Figure 13. Acoustic biomass of Jack mackerel in the Peruvian sea from 1983 to 2011

Estimated acoustic biomasses of jack mackerel (usually covering an area from 0 to 100 nm from the coast) have been extremely variable, ranging from 8.5 million tons in 1983 to 1,200 tons in 2010 (Fig. 13). Two periods can be easily observed from this series, one of great availability between 1983 and 1996, and the other of low availability from 1996 to date.

3.3 Reproduction and recruitment

The period of maximum maturity and spawning activity of the jack mackerel off Peru extends from winter to the next summer, with the higher spawning intensity in spring (Santander and de Castillo, 1971; Santander and Flores, 1983; Orrego, 1982; Peña and Mariategui, 1988). It has also been observed that the jack mackerel has a permanent center of main spawning in the Peruvian sea, which tends to spread along the entire coastline with some variations that appear to be related to observed decadal and regime climatic changes in the Southeast Pacific.

Some bio-oceanographic surveys conducted in the 1980s provided valuable information to better understand the environmental conditions in the main spawning areas of Peruvian jack mackerel located between 14º00'S and 18º30'S (Santander and Flores 1983, Dioses *et al*, 1989). It was found that these spawning areas were in the oceanic front limited by the CCW (salinities lower than 35,0 ups) and SSW (salinities higher than de 35,1 ups), with temperatures above 18ºC and oxygen content around 5,0 mL/L. In these water columns the spawning schools of jack mackerel tend to be located at depths between 10 and 80 m, with an ideal salinity of 34,9 to 35,1 ups, a temperature of 15º to 18ºC and an oxygen content from 3.0 to 5.0 mL/L.

The fact that the spawning of jack mackerel takes place mainly in this area, within the euphotic zone and over the 50 m, explains why the areas of larvae distribution tends to extend further offshore, more than the 200 miles from the coast, since these would be transported offshore by the larvae drift caused by the Ekman transport.

3.4 Reproductive cycle

Seasonality of maturity and spawning has been determined using the monthly Gonadosomatic Index (GSI), measured since 1967. The available information confirms that jack mackerel has spawned permanently off Peru in the last 50 years, with maximum periods of maturity and spawning usually between September and December, with a peak in November. A higher frequency of months with high GSI values has been observed during the decades of the 1980s and 1990s with more disperse but still important pulses in the 1960s-1970s and from 2000 to date (Fig. 14).

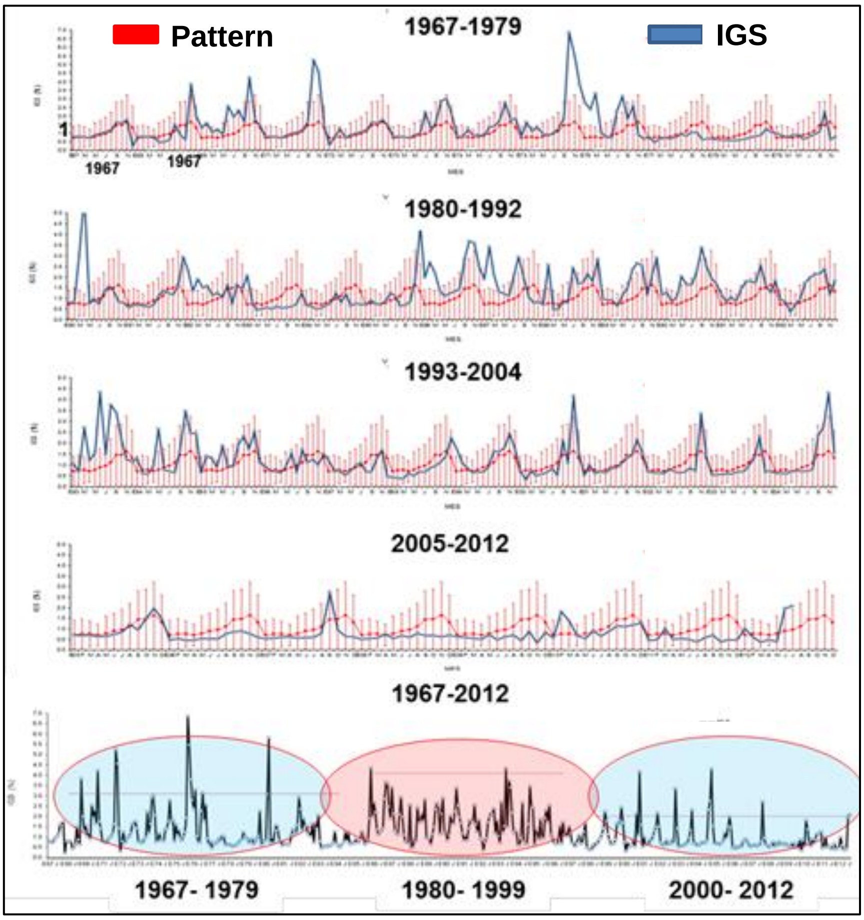

Figure 14. Monthly gonadosomatic index of jack mackerel from 1967 to 2012

3.5 Size at first maturity

The length at first maturity was estimated in 26,5 cm total length, as average of the period of 1967-2012 (Fig.15 and Table 2). There is no trend in the series although some slight fluctuations can be noted. This is an important trait, since absence of a declining trend is indicative that this stock of jack mackerel has reproduced and is reproducing normally to date, without showing signs of "reproductive stress" typical of overexploited or depressed stocks which usually tend to mature earlier as a result of overfishing.

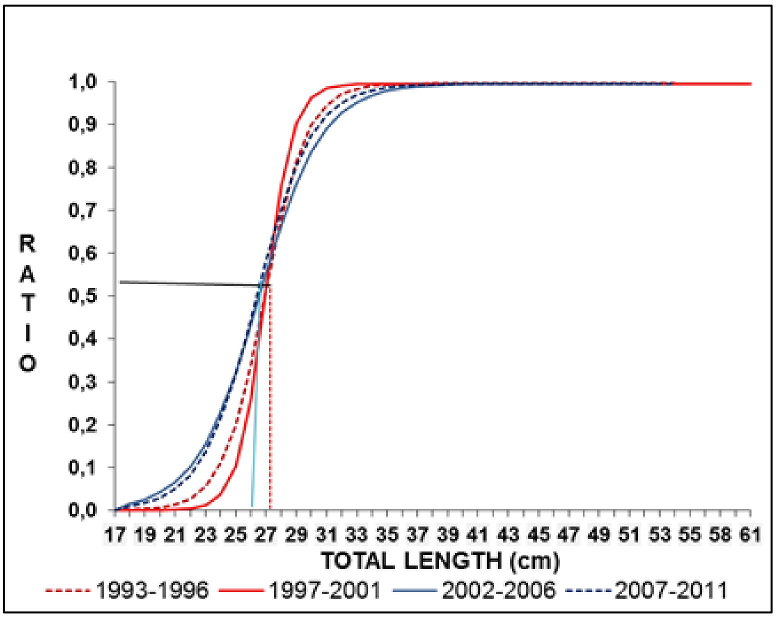

Figure 1. Ojive at first maturity of the Jack mackerel (1993-20119

Table 2. Length at first maturity ($L_{50\%}$) of jack mackerel Peru (1967-2012)

1967-1969	24.5
1971-1972	---
1973-1974	27.0
1975-1976	---
1977-1978	24.3
1979-1980	25.6
1981-1982	25.3
1983-1984	21.1
1985-1986	27.0
1987-1988	21.9
1989-1990	25.8
1991-1992	24.7
1993-1994	25.7
1995-1996	27.2
1997-1998	25.1
1999-2000	26.0
2001-2002	26.9
2003-2004	27.8
2005-2006	25.6
2007-2008	25.6
2009-2010	25.1
2011-2012	25.0

3.6 Distribution and abundance of jack mackerel larvae

Available data on relative abundance of jack mackerel larvae from egg and larvae surveys conducted during the period 1966-2012 have recently been compiled and analyzed by IMARPE and Fig. 16 shows the yearly estimates of average abundance considering all the stations (top plot, blue dots) and mean abundance considering only positive stations (lower plot, red dots). The estimated mean for the positive stations rangesfrom 3 to 1131 larvae/m^2, witha median of 21 larvae/m^2. On this, it is noted that in general, the frequency and abundance levels have been variablebut without any particular trend for the56 year period being analyzed.

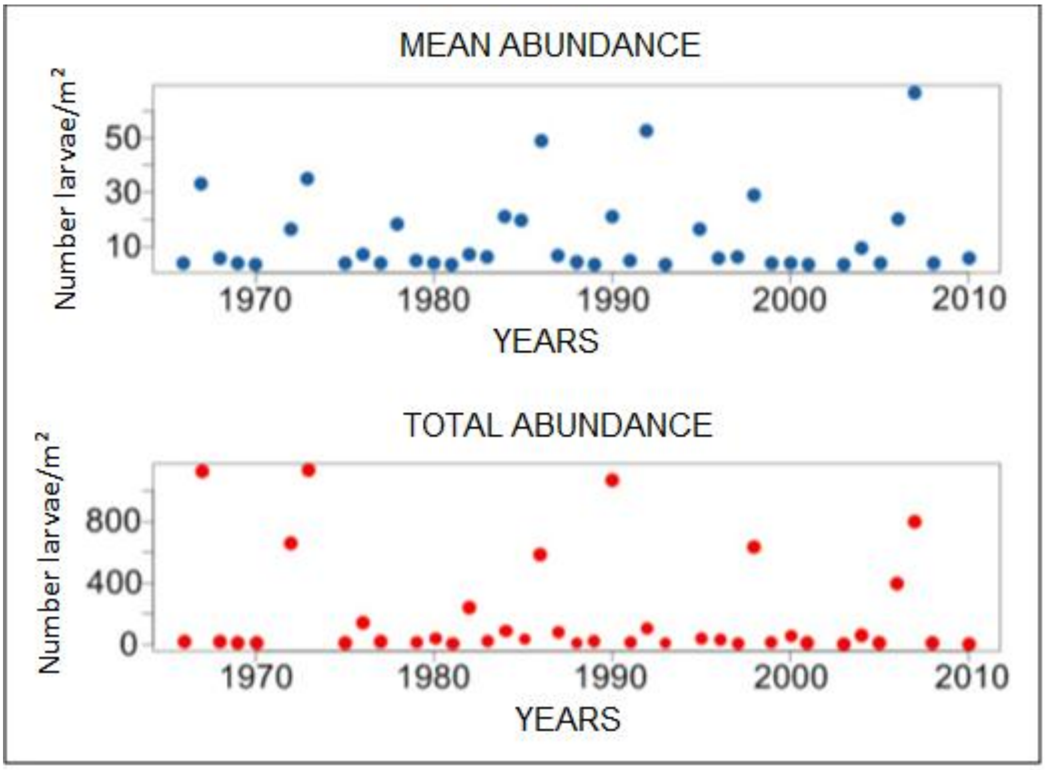

Figure 16. Average and total abundance of larvae of jack mackerel from 1966 to 2010

However, important changes with time were found in the spatial distribution of the larvae (Fig. 17). From 1970 to 1979 jack mackerel larvae were present particularly in the southern zone of Peru, while during the period 1980-1989 there was wide distribution from the north to the south with higher densities north of Punta Falsa (06ºS), and during the period 1990-1999 the distribution was mainly north of the 16ºS, with an expansion toward the south between 2000 and 2010.

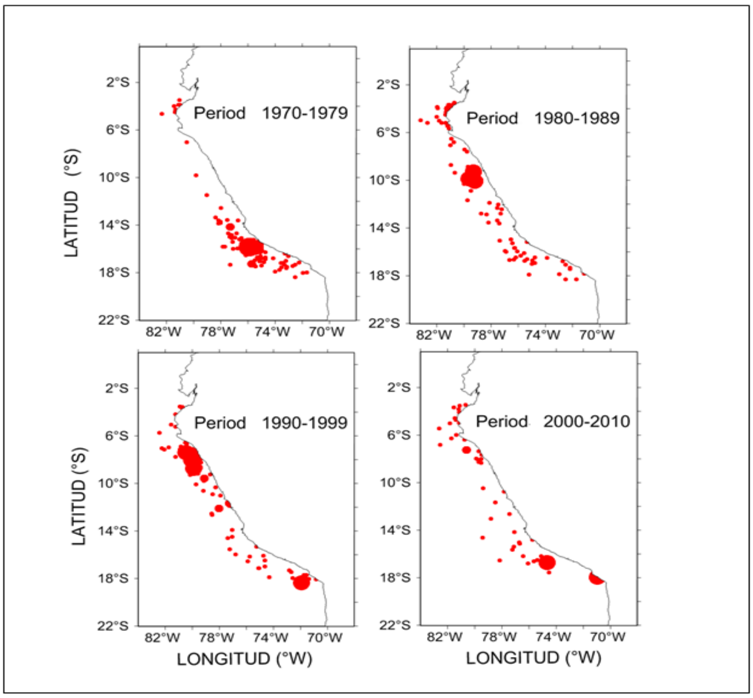

Figure 17. Distribution pattern of Jack mackerel larvae (1970-2010)

The centers of gravity of the larvae spatial distribution was calculated for every year (Fig. 18) showing some important differences between decades, with three clear periods: the first one between 1966 and 1978 located between 14°S and 18ºS, more coastal; the second between 1979 and 1994 located northward, between 4°S and 14ºS, more offshore; and, the third between 1995 and 2010, located in an intermediate position between the other two.

If we consider that during most of these years the Peruvian fishery has exerted a very low fishing pressure on the available biomass of jack mackerel as estimated by the acoustic surveys in the neritic zone, these observed decadal changes in the dynamics of the spawning areas cannot be related to possible effects of fishing and can be best explained by the possible effects of similar time-scale changes in the marine climate, already described in the chapter on marine environment in this report.

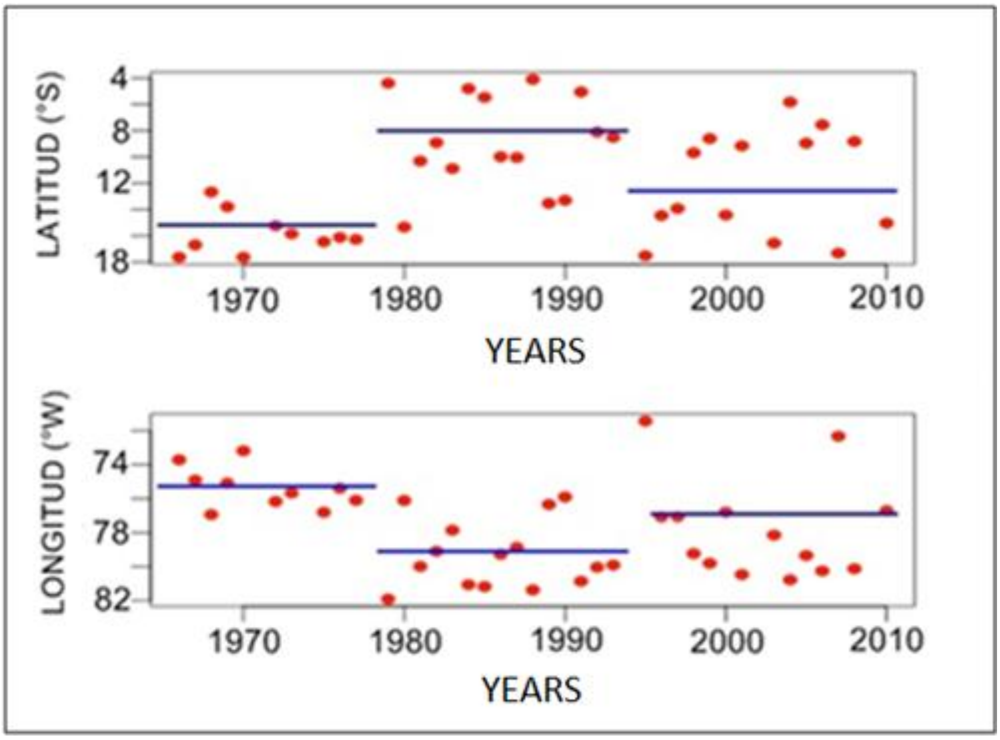

Figure 18. Annual distribution of the abundance gravity centers of the Jack mackerel larvae in the Peruvian sea

3.7 Feeding

The analysis of the samples of stomach content of jack mackerel regularly collected both from the fishery as well as from scientific surveys between 1977 and 2011 shows two temporal scenarios in the diet of this species off Peru (Fig. 19): the first one from 1977 to 2000, with an important dominance of euphausids; and the second one from 2000 to the present, with a significant presence of squat lobster (*Pleuroncodes monodon*) and zoeas (crustacean larvae), besides euphausids. These two scenarios are well correlated with the climatic interdecadal variability described above and correspond to the above mentioned warm and cold climate regimes respectively (Chavez *et al*., 2003; Espino, 2003; Chavez *et al*., 2008).

It is interesting to note that the presence of squat lobster in the stomach content of jack mackerel during the second period (2000 to date) is related to the depth of the 15°C isotherm, which in turn is strongly correlated with the depth of oxygen minimum zone (OMZ) (Bertrand, 2010). When the OMZ deepens, favors the approach to the coast of jack mackerel, expanding towards the richer coastal zones the habitat suitable for this species (Bertrand, 2004). In this way it can feed on neritic and coastal species, like squat lobster.

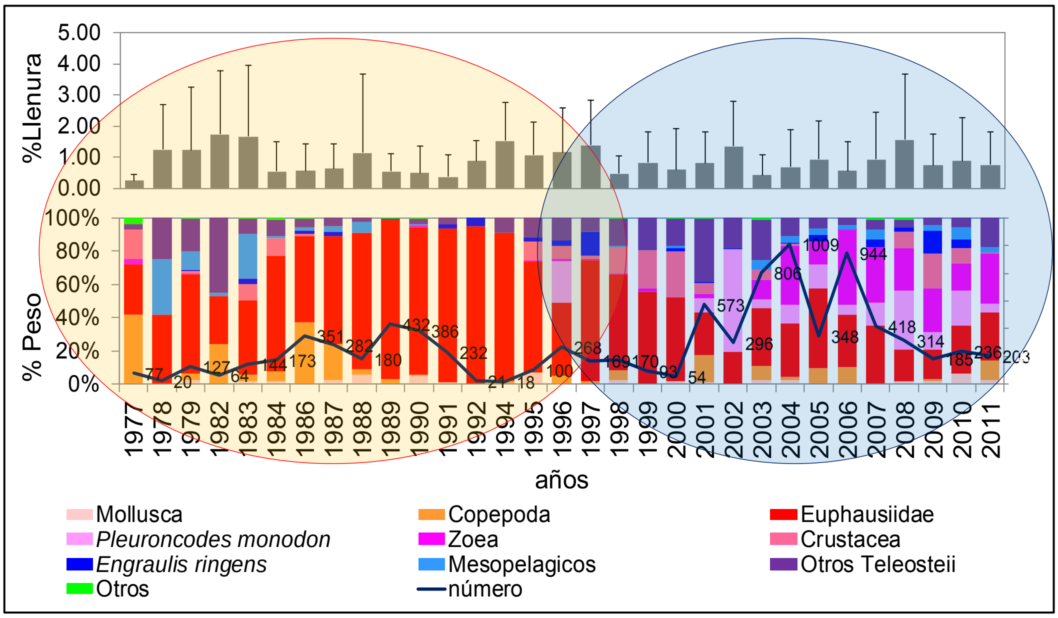

Figure 19. Stomach fullness index and proportion of prey in stomachs of jack mackerel off Peru (1977 to 2011)

From the analisis of stomach content by size it is noted that as the jack mackerel grows and matures, the relative weight of the stomach content declines and the proportional ingestion of euphausids increases. According to Sánchez de Benites *et al* ., (1985) and Sánchez and Muck (1987), the jack mackerel off Peru has an opportunist feeding strategy, becoming ichtyophagous or zooplanktophagous depending on the prevailing environmental conditions, and available food sources. During the 1960s there was a high incidence of anchoveta in the jack mackerel diet, besides euphausids, *Pleuroncodes monodon*, copepods and *Loligo* sp. (Mejía *et al*, 1970; Paredes, 1972), while at the beginning of the 1970s there was a more mixed diet (Druzhinin y Konchina 1973; Konchina 1980).

A certain differentiation of diet by latitude has also been observed (Fig. 20). Euphausids were more dominant in the north, while the diet was more diversified to the south of 10°S (center-south region) including zoeas, mesopelagics and squat lobster (*P. monodon*), an indicator of Cold Coastal

Waters (CCW). Dioses (1995) reported that the main prey of the jack mackerel between 1977 and 1981 was anchoveta, with longnose anchovy (*Anchoa nasus*) in the north of 7ºS and mictophids in the south of 13ºS. However, during El Niño 1982-83 this feeding behavior was modified because the absence of anchoveta, with elements of the zooplankton community specially euphausids and copepods becoming the main preys of the jack mackerel during this El Niño.

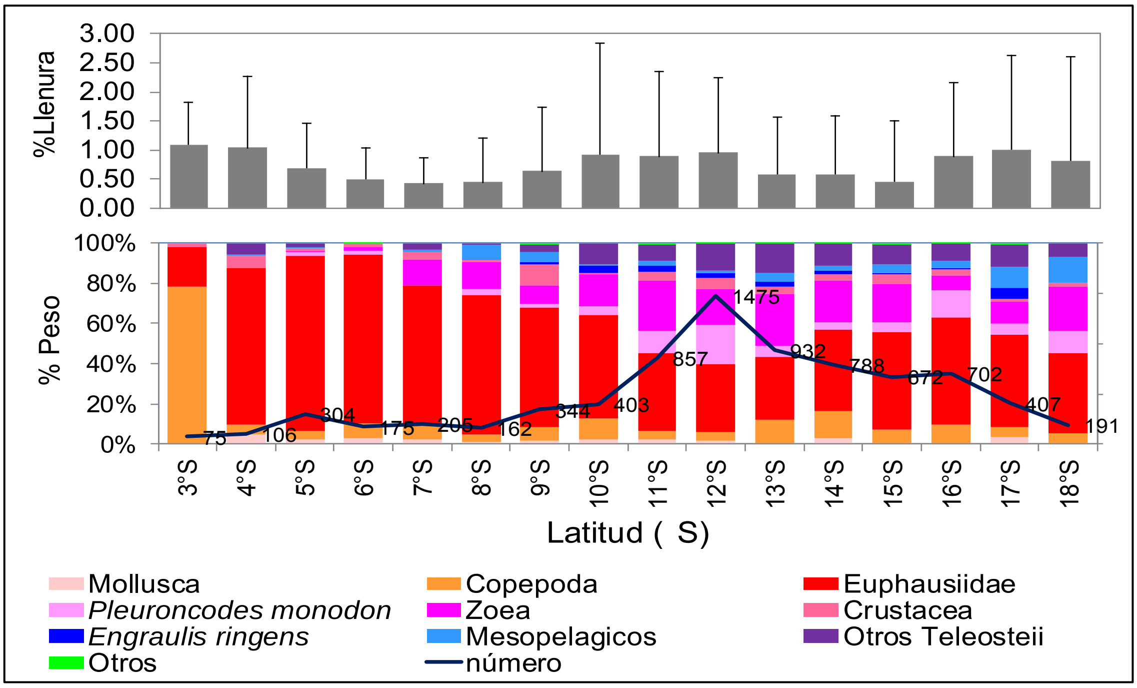

Figure 20. Stomach fullness index and proportion of prey of jack mackerel by latitudes (ºS) from 1977 to 2011

The analysis of the stomach content by distance from the coast shows that the index of stomach fullness decreases as the distance from the coast increases. There are reports describing jack mackerel as a facultative and opportunistic predator in the Peruvian pelagic ecosystem, feeding on both neritic as well as oceanic epipelagic environments (Konchina, 1980, 1983; Medina y Arancibia, 2002), getting closer to the coast in spring and summer, and more westward in fall and winter (Muck & Sánchez, 1987; Zuzunaga, 1986).

3.8 Age and growth

Age and growth studies have been conducted based in direct readings of otoliths as well as on analysis of the size frequency distributions of samples taken from commercial catches and scientific surveys.

3.8.1 Otolith readings

The age determination by reading rings in otoliths included the validation of the first annual ring, studies on the increment of the otoliths radius to the second and third ring, and the identification of annual rings.

a) Validation of the first annual rings

An analysis of micro-increments was made to validate the first annual ring under the assumption that from the center to the border there should be 365 of them (Araya *et al,* 2003). Daily increments were read in 31 otoliths from samples of juvenile individuals captured in the summer of 2011 in the southern region of Peru (Table 3). A Gompertz growth model was fitted to the observed readings obtaining a significant fit (p<0.001) and estimating that a one year old individual would have a total length of 195.3 mm (Fig. 21).

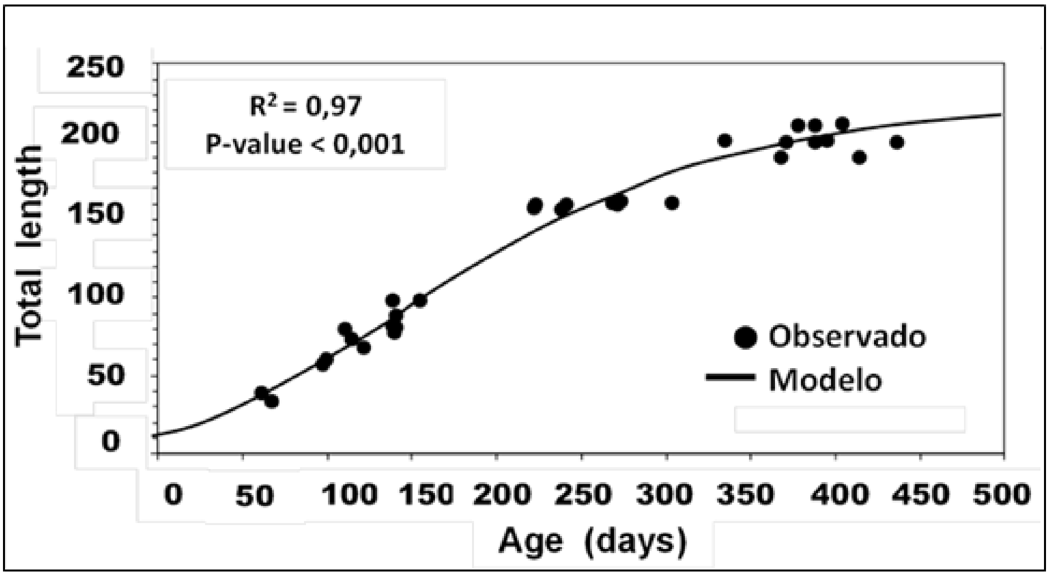

Figure 21. Daily growth curve of jack mackerel. Adjusting to a Gompertz curve.

Table 3. Total length (mm) and number of daily increments in 31 otoliths of jack mackerel sampled off southern Peru, during the summer of 2011

N° ind	Long. (mm)	N° increments or age (days)
1	35	65
2	38	59
3	57	96
4	58	99
5	67	123
6	71	115
7	96	139
8	84	139
9	89	144
10	81	145
11	79	111
12	78	141
13	98	156
14	162	303
15	155	240
16	190	369
17	160	225
18	156	224
19	159	274
20	161	270
21	163	278
22	160	245
23	200	335
24	190	415
25	200	396
26	200	375
27	200	437
28	200	391
29	210	380
30	210	390
31	210	405

b) Increment of the otoliths radio (to the second and third ring)

The age determination from otolith readings is based on a correct identification of the first ring and on the correct discrimination of the remaining ones. So, age readings are based in assigning one year of age to each clearly defined ring, excluding from the counting the so called false rings. For the smaller individuals it was also possible to assign the age by measuring the otolith radio, having been determined that the mean radio of an otolith of one year old fish is 2.47 mm, of a two year old fish is 3.36 mm, and of a three year old fish is 3.97 mm.

One way of crosschecking the age assigned to clearly defined rings is by following in a cohort the monthly increments of the total radio of otoliths from one year to the next. And in this respect, it is noted that during 2011 and the first part of 2012 the catches of jack mackerel off Peru were mostly based on a single cohort, as can be observed from the monthly length frequency distributions of catches (Fig. 22), where the mode in the size frequencies was 28 cm in January 2011 and 36 cm in January 2012. Monthly biological samples from this cohort were available from the regular IMARPE sampling program and from this, monthly samples of otoliths of this cohort were collected for age readings. At the beginning of the period the otoliths had an average total radio of 3.32 mm (mostly with two rings) while at the end of the period some of the otoliths started to show a third ring and had an average total radio of 3.94 mm (Table 4). In the twelve months the otoliths had grown an average of 0.62 mm (Fig. 23). These results supported the age assignation in the readings of otoliths rings.

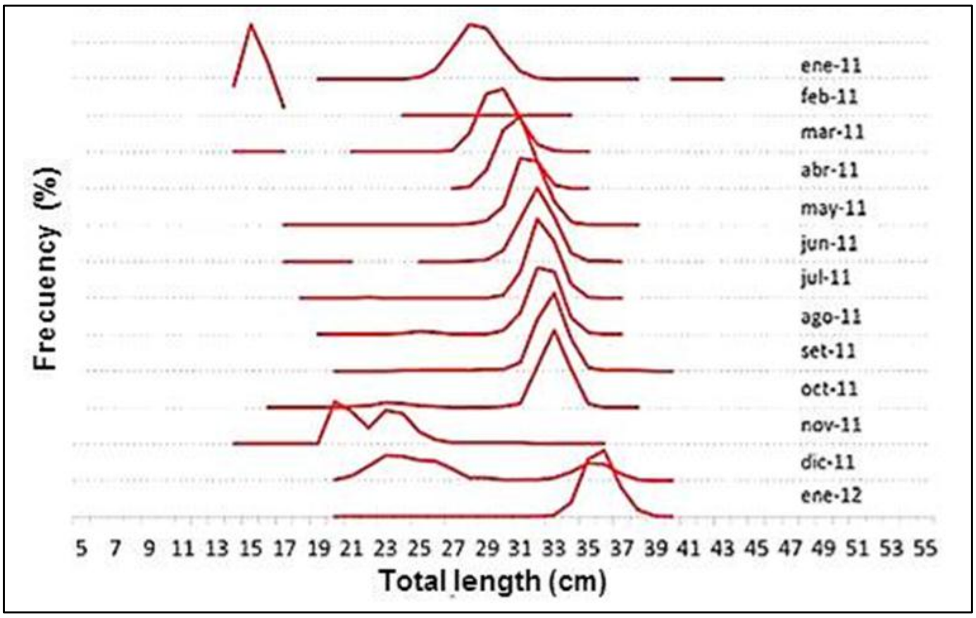

Figure 22. Size frequency distributions of jack mackerel caught in Peru, by month, January 2011 – January 2012

Table 4. Observations from the monthly sampling of otoliths from a cohort of jack mackerel off Peru, January 2011-January 2012

Sampling date	No. of days ellapsed	Mean length of the fish (cm)	Mean radio of the otolith (mm)
19/01/2011	0	27.8	3.32
07/02/2011	18	28.9	3.42
14/03/2011	51	29.7	3.53
18/04/2011	86	31.1	3.54
11/05/2011	119	31.1	3.60
21/06/2011	159	32.2	3.70
22/07/2011	190	32.8	3.68
17/08/2011	215	32.7	3.75
14/09/2011	242	32.8	3.77
27/10/2011	285	32.8	3.81
17/01/2012	365	35.5	3.94

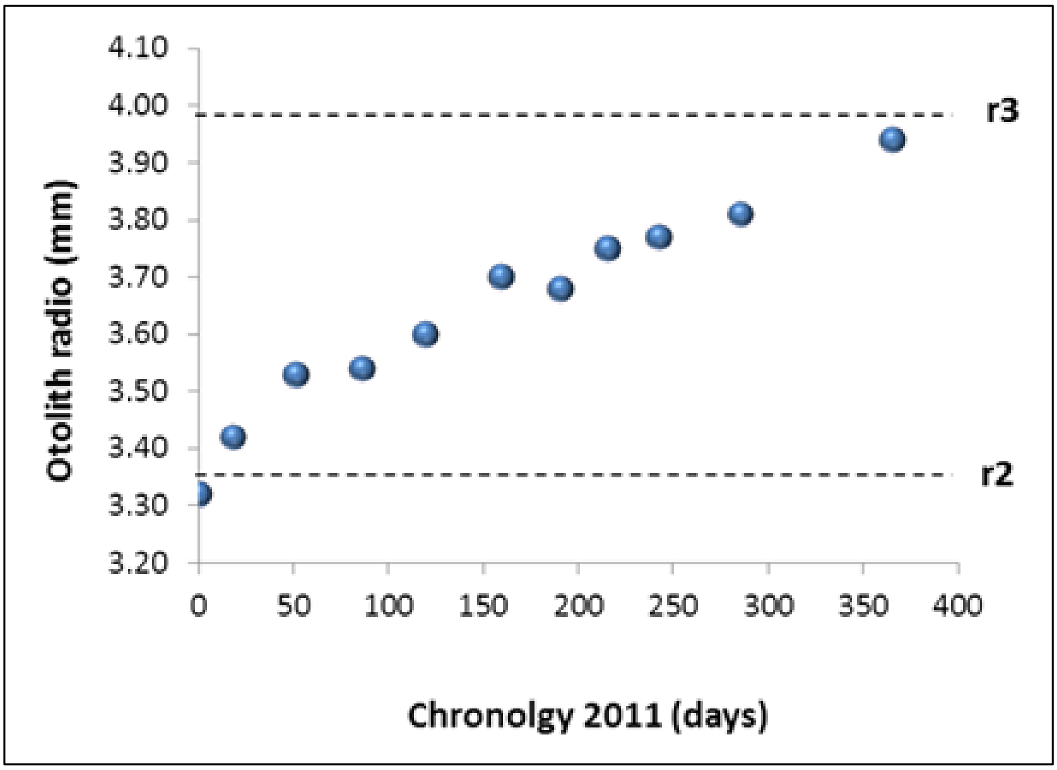

Figure 23. Average radius of the of the otoliths of jack mackerel (January 2011 – January 2012)

c) Annual rings readings

Readings of the two sets of otoliths were undertaken in two different periods of time and allowed the determination of the number of ages and of growth parameters. In both cases the standard methodology included the preparation of the otoliths, reading of annual rings and age assignation, concluding with an age-length key.

The first case used a sample of 977 otoliths of jack mackerel collected at the main landing ports during the years 1977–1979. The sample had a wide range of sizes with individuals ranging from 3 to 71 cm of total length. The von Bertalanffy growth parameters were estimated with the Ford–Walford graphic method and the parameter t_0 was estimated with the equation of Gulland (1977). The maximum number of observed rings was 11 and the estimated growth parameters were: L_∞ = 80.77 cm, K = 0.16 per year and t_0 = -0.356.

The second case used a sample of 1179 otoliths also collected along the whole Peruvian coast during 1995. The fish samples had sizes ranging from 6 to 60 cm of total length. To avoid the possible underestimation of L_∞ due to the absence of the larger sizes, it was decided to maintain this parameter fixed at 81 cm during the adjustment process to estimate the other growth parameters. The maximum number of observed rings was 7, the mean length for each group varied between 9.5 y 53.7 cm and the estimated growth parameters were K = 0.16 per year and t_0 = -0.587.

3.8.2 Length frequency analysis

In addition to estimating the age and growth parameters through the direct age readings from otoliths, the growth parameters were also estimated through the length frequency analysis (LFA) (Pauly and David, 1981; Pauly, 1987). These are indirect, non-parametric methods, totally independent from the age readings from hard structures. The asymptotic length (L_∞) was estimated from the maximum observed length (79 cm) using the method of Froese and Binohlan (2000). The estimated L_∞ was 81.6 cm, with a lower limit of 68.8 cm and an upper limit of 96.7 cm, and this used as input for the estimation of the other growth parameters using FiSAT (Gayanilo, *et al* ., 2004).

A total of 446 vectors corresponding to the period January 1972 – April 2012 were built and analyzed, and included fish with total lengths ranging from 5 cm to 79 cm. As observed in Fig. 24 and Fig. 25, before 1993 the size frequencies have modes between lengths of 30 and 40 cm that are relatively constant (without a clear temporal succession) and it is only after this year that the recurrent appearance of different modal groups whose growth could be followed during several months becomes evident. Consequently, only the size frequencies for the period 1993-2012 were used in the fitting using the LFA.

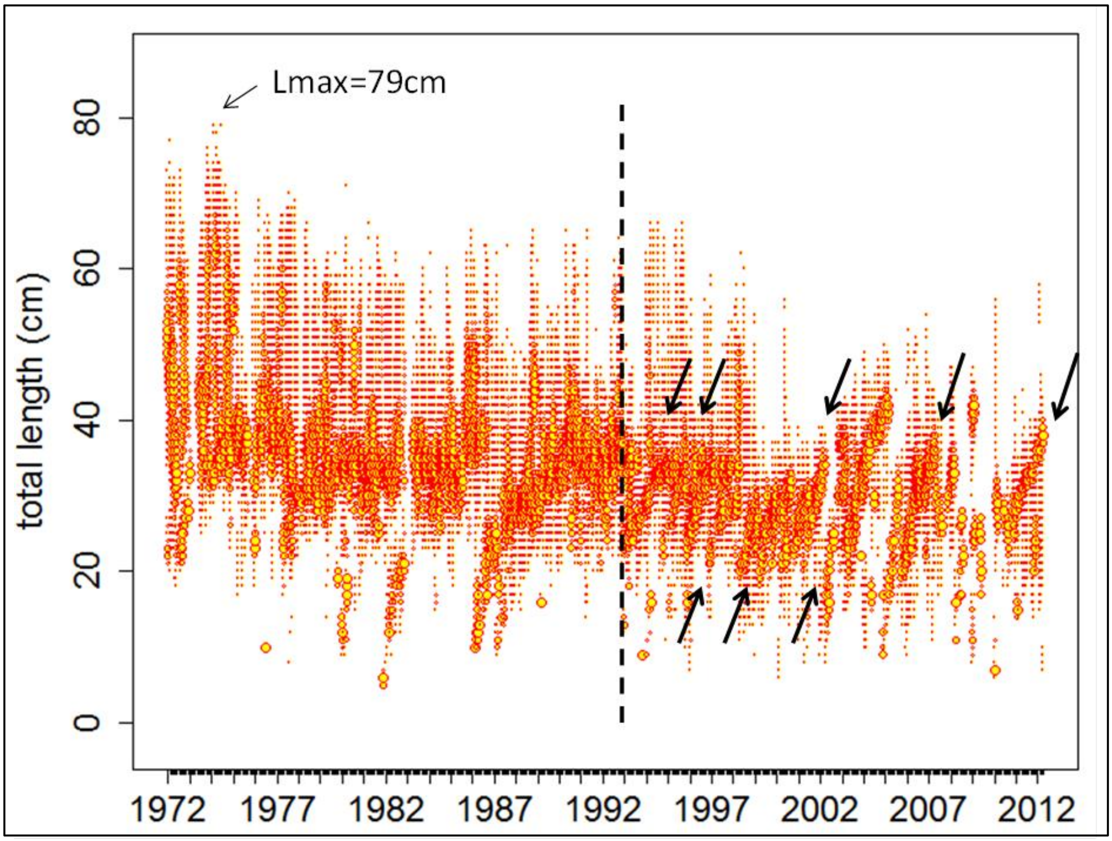

Figure 24. Monthly length distribution of jack mackerel catches in the Peruvian sea, showing the highest size between 1972 and 2012

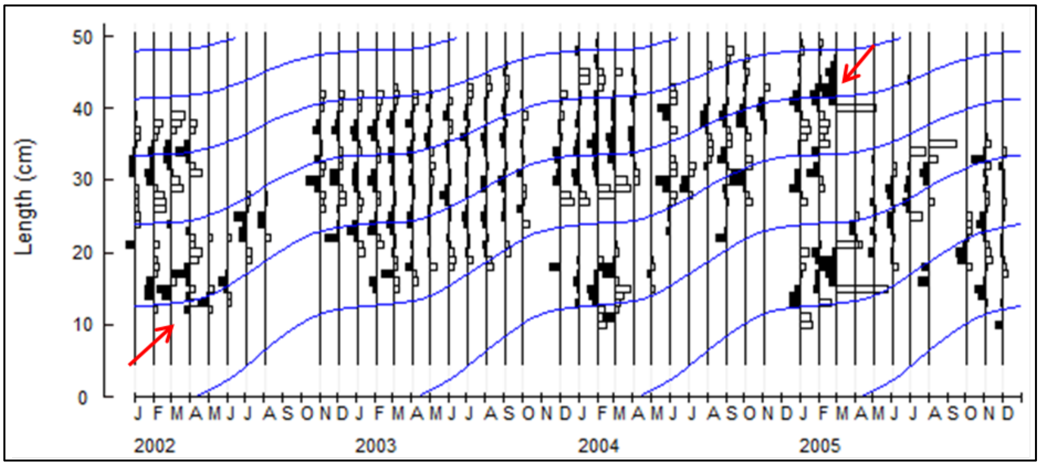

Figure 25. Growth curves adjustment to the temporal succession of age groups identified in the horse mackerel fishery since January 2002 (bottom left red arrow), with a mode at approximately 15 cm, until March 2005 (top right red arrow), with a mode of approximately 40 cm.

One of the age groups of jack mackerel was followed for up to four years through the temporal succession of available modes while other single modes (age groups) could only be followed consecutively during one or two years. Thereafter the modes tended to faint being overshadowed by the appearance of a new age groups. The estimates of the growth parameter K obtained for each year or pair of years are shown in Table 5.

Table 5. Estimates of K for the period 1993 - 2012

Age group followed during the analysis	**K (y^{-1})**
1993	0.15
1995	0.17
1996	0.16
1998	0.18
1999	0.18
2000	0.15
2001	0.16
2003-2004	0.18
2006-2007	0.17
2011-2012	0.17
Mean	0.17

The above estimates confirm that the jack mackerel off Peru grows with an annual K that fluctuates around 0.17, which is very similar to the estimates obtained with the direct methods. In this respect, it is noted that the results obtained for the jack mackerel off Peru and presented herewith (L_∞ = 80.77cm, K= 0.16 per year and t_0= -0.356 to 0.587) are significantly different from those obtained by other authors for the jack mackerel captured off Chile, where $L\infty$ = 70.8 cm, K = 0.094 per year and t_0 = -0.896 (Gili *et al .*, 1995).

3.9 Resource-environment relationships

The oceanic front between the ASS and the CCW is the preferred habitat of jack mackerel off Peru. Its complex dynamics determines the main characteristics of this stock unit, such as its general distribution, spawning areas, spawning seasonality, food consumption, growth rate, etc.

Jack mackerel schools off Peru are mainly found in water columns where the sea temperature ranges between 14°C and 20°C. Nearer to the coast where the isotherms are farther apart in the water column the jack mackerel schools expand their vertical distribution. The depth of 15°C isotherm represents the divergence among isotherms in water column near the coast (Flores *et al .* 2009) and the presence and concentrations of jack mackerel off Peru nave been found to be related to this variable.

Icochea, *et al* (1989) and Chirinos (1992) described and analyzed the vertical distribution of jack mackerel and chub mackerel based on the catch records of Cuban and ex-Soviet Union fleets that operated off Peru between February 1983 and March 1987. Then Ganoza (1998) described the distribution and abundance of jack mackerel in relation to the environmental conditions during acoustic surveys conducted between 1983 and 1994, and Dioses *et al .* (1989) described the characteristics of the bathymetric distribution of spawning schools detected between October and December of 1986 in relation to temperature, salinity and oxygen content measured in vertical oceanographic profiles in the same places. From the results of all these studies one may conclude that the jack mackerel off Peru has three distinct behavioral patterns which can be related with the diverse prevailing environmental conditions usually found off Peru (Fig. 26), as follows:

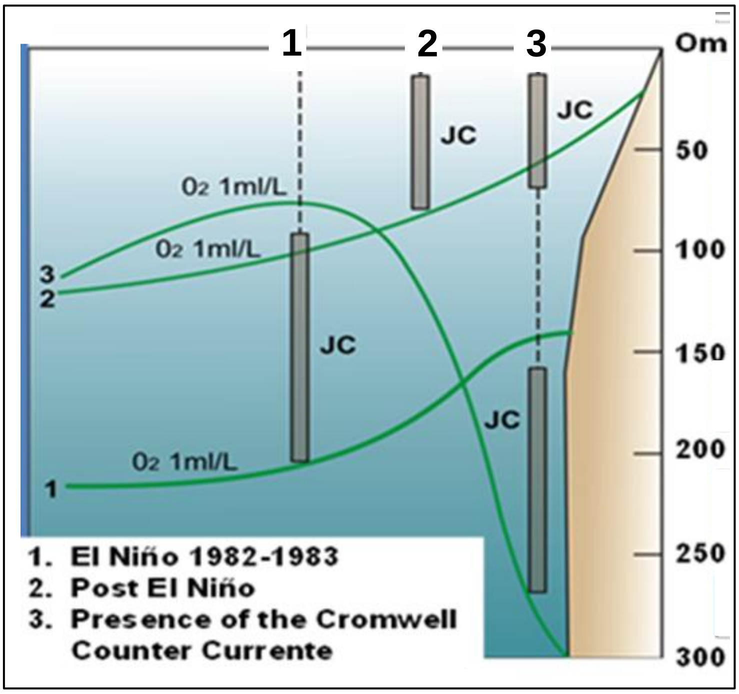

Figure 26. Vertical distribution pattern of Jack mackerel and the isoxigen line of 1 ml/l of oxygen content

1) During El Niño events, pelagic species such as the jack mackerel are located below a well-defined and deep thermocline. Catches are taken at depths of 100m or more, within a temperature ranging from 15°C to 20°C, salinities between 35.0 and 35.1ups and oxygen contents higher than 1.0 ml/L. Under these conditions the jack mackerel is mostly vulnerable and available to mid-water trawling;
2) During a post-El Niño period, the thermocline and also the 15°C isotherm becomes shallower, CCW dominates the scenario with salinities below 35.1 ups and oxygen contents of 1.0 to 3.o ml/L. Fish concentrations also become shallower, with a reduced availability related to the dynamics of the oceanic front; and,
3) During non El Niño conditions where there is a strong presence of the Southern Extension of Cromwell Current, which becomes evident by the deepening of the 14°C and 15°C isotherms near the coast,

fishing becomes more coastal, nearer to the surface during night and deeper in the morning.

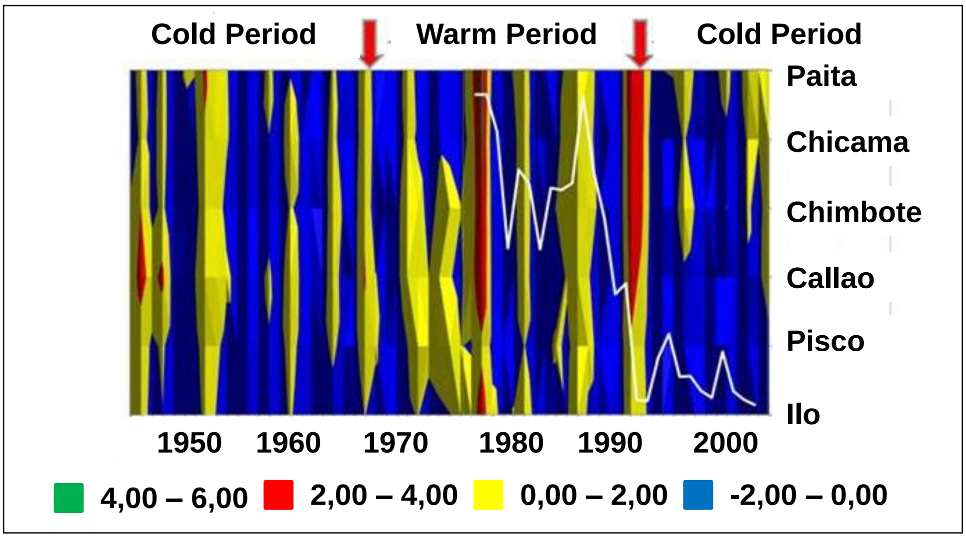

Figure 27. Sea Surface Temperature anomaly from Paita to Ilo (1950-2010) and jack mackerel acustic Biomass (1983-200).

These patterns can be also be noted in relation to larger scale interdecadal changes in environmental conditions and in fact, the second behavioural pattern described above would correspond to the current cold climate regime, which could explain the current jack mackerel dynamics off Peru. The same could be said for previous time-periods where short to medium term changes in the marine climate seem to have caused strong effects on the dynamics of the Peruvian jack mackerel stock. The interdecadal warm period of the mid-1970s to 1980s provided the most appropriate conditions for the development of jack mackerel off Peru, as suggested by the availability of high biomasses of jack mackerel in the neritic zone estimated by acoustic surveys. To the contrary, the interdecadal cold periods as of the 1950s to mid-1970s and from 2000 to date are less suitable for the development of jack mackerel, making it less available in the Peruvian sea.

4. DESCRIPTION OF THE FISHERY

The important presence of jack mackerel from Paita (05°S) to Mollendo (17°S) including catches of large specimens (more than one meter) in the area of Lobos de Tierra was reported in a 1907 description of the Peruvian fishery

(Coker, 1908 y 1910). More recent available landing statistics from the 1960s placed the jack mackerel within the three most important pelagic species and as the second one after the anchoveta since 2000.

Before 2002, around 500 vessels out of the 1200 that were part of the industrial purse seine fleet directed their fishing effort to jack mackerel, mainly during the closed anchoveta fishing seasons. Since 1974, the majority had fishing nets and fishing systems that allowed them to indistinctly fish for one or the other of the above mentioned pelagic species. However, during 2002 the Supreme Decree (D.S. 001-2002 of 06-09-2002) established that jack mackerel and chub mackerel could only be caught and used for direct human consumption, causing a drastic modification of the 'jack mackerel' fleet and the reduction of the total catches of this species since it was not allowed to catch it or use it for the production of fish oil or fish meal. Furthermore, this new regulation promoted the development of an industrial fleet with refrigerated sea water (RSW) system in addition to other characteristics specific for fishing for direct human consumption (DHC).

4.1 Characteristics of the purse seine fleet

The Peruvian purse seiner fleet dedicated to jack mackerel mostly operates in the coastal area along the Peruvian coast, mostly within the first 100 nm from the coastline. The main characteristics of this industrial purse seine fleet are summarized as follows:

Characteristics	**Purse Seine (Peruvian fleet)**
Fishing gear(method)	ACTIVE (Superface)
Type of fishing	Encircling
Material of nets	Robust , highdensity
Schools	Plumes or larger concentrations, near the surface
Volumes	More than 500 t per set
Coverage	Coastal
Days of effective operation	4-5
Number of sets per day	01-04
Catch processing	Fresh in refrigerated water
Coolingsystem	Refrigerated Seawater (RSW). Chilled Seawater (CSW)

In 2006 the operative industrial fleet authorized to fish for jack mackerel in the Peruvian waters comprised 511 vessels, of which 53 were steel vessels and 458 wooden vessels. The total holding capacity of the whole fleet was 50 587 m^3, with 21 695 m^3 for the steel fleet and 28 892 for the wooden fleet (Table 6).

Table 6. Structure of the industrial fleet authorized to fish for jack mackerel in 2006

Type of vessel	Hold capacity range (m^3)	No. of vessels	Total hold capacity	Average hold capacity.
Steel	30-100	5	364	73
	101-200	7	947	135
	201-300	3	810	270
	301-400	8	2978	372
	401-more	30	16596	553
Total Steel		53	21695	409
Wood	30-50	205	7857	38
	51-100	192	14524	76
	101-110	61	6512	107
Total Wood		458	28892	63
General total		511	50587	94

As part of a process of optimization, in 2011 the fleet authorized to fish for jack mackerel in Peruvian waters was reduced to 104 vessels, of which 62 were steel and 42 wooden vessels. The total hold capacity of the whole fleet is 33 359 m^3, with 30 177 m^3 corresponding to the industrial steel fleet and 3 082 to the wooden fleet (Table 7).

Table 7. Number and hold capacity (m3) of the purse seine fleet authorized to fish for jack mackerel, year 2011

Wooden vessels (using boxes/ice)			
Range m3	Number	Total hold capacity	Average hold capacity
31 - 60	14	556	39.7
61 - 90	13	991	76.2
91 - 110	15	1535	102.3
Total	42	3082	73.4

Steel vessels (using Refrigerated Sea Water)			
Range m3	Number	Total hold capacity	Average hold capacity
111 - 300	2	348	174.0
301 - 400	6	2167	361.2
401 - 500	29	12913	445.3
501 - 600	19	10537	554.6
601 - 700	4	2477	619.3
> 700	2	1735	867.5
Total	62	30177	486.7

The number of purse seiners that actually fished for jack mackerel during the period 1970 – 2011 is plotted in Fig. 28. The maximum was in the 1990s with around 700 vessels, but then declined and remained relatively constant below 100 since 2002.

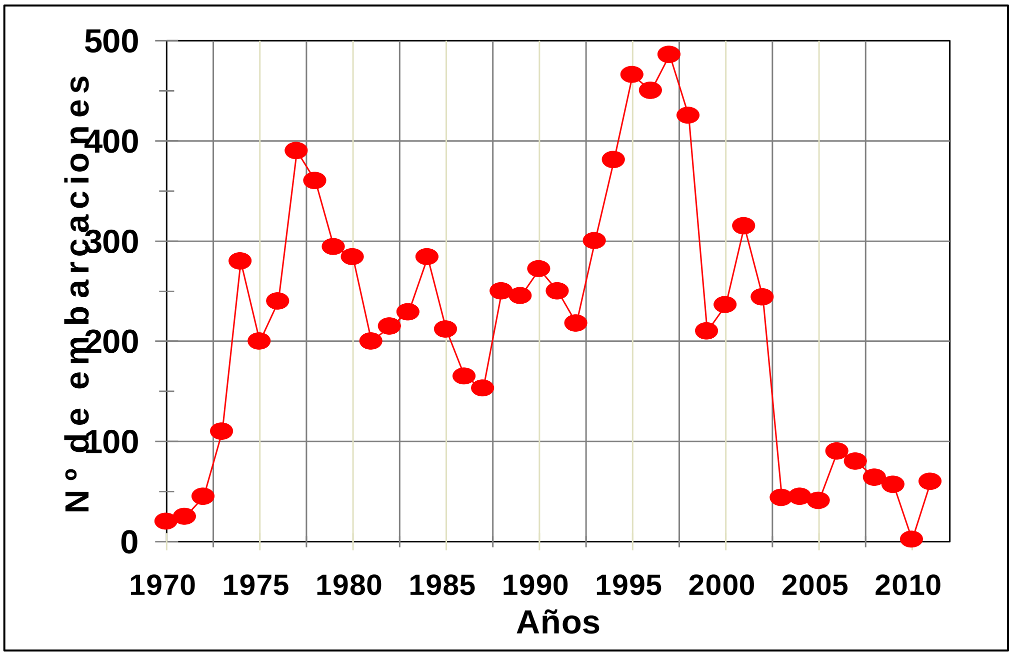

Figure 28. Number of vessels for jack mackerel fishery in Peru during 1970-2011

4.2 Catch trends

There are reports on jack mackerel catches in the Peruvian sea since the beginning of the last century (Cocker, 1908) and historical catch records show that there were regular catches of jack mackerel off Peru since 1939 (Fig. 29), although these did not exceed the 10 tons per year until the 1950s. In the 1950s catches were in the order of a few hundred tons per year, and in 1963 catches almost reached two thousand tones. In 1974 catches increased to more than 100 thousand tons and to more than 500 thousand ton in 1977. After 1977 the annual catches were kept between 100 and 400 thousand tons, except for the maximum recorded 710 thousand tons in 2001.

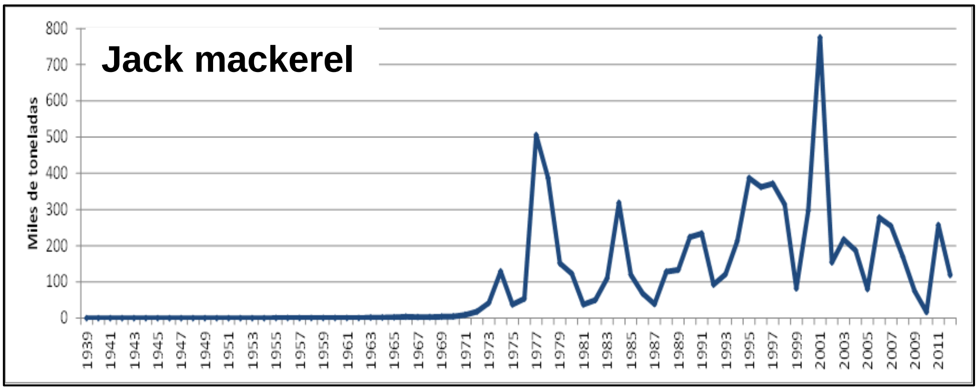

Figure 29. Landings of jack mackerel in Peru, 1939-2012

The annual landings of jack mackerel in the period 2002 – 2011 show a clear decreasing trend since 2007, with a minimum in 2010 due to the low availability of jack mackerel. However, the increase of jack mackerel catches during 2011 has partially reversed the decreasing trend observed in recent years. This year (2012) the industrial fleet has reported almost 119 thousand tons (Table 8).

The historical information on latitudinal distribution of jack mackerel catches along the Peruvian coast shows a wider distribution until 1998, with high indexes of abundance especially between the 1970s and 1998, with catches fluctuating between 50 and 500 thousand tons per year. Since 1998, the distribution of the catches is mainly concentrated in the center-south region and the annual catches fluctuated at a lower level than the previous period, with the exception of 2001 when the catch was 775 thousand tons. In the period 1970–2012 there was a strong seasonality in the jack mackerel catches (Fig. 30), with best catches in summer and spring. The last years the best catches were concentrated mostly in summer.

Table 8. Jack mackerel catches off Peru (in tons), by fleets, 1939-2012

year	Purse seine	Trawl	year	Purse seine	Trawl	year	Purse seine	Trawl
1939	10		1964	1718		1989	57516	83204
1940	34		1965	2561		1990	90544	100595
1941	46		1966	4271		1991	92212	44125
1942	15		1967	3071		1992	96660	
1943	13		1968	2790		1993	130681	
1944	23		1969	4176		1994	196771	
1945	17		1970	4711		1995	376600	
1946	43		1971	9189		1996	438736	
1947	59		1972	18782		1997	649751	
1948	44		1973	42781		1998	386946	
1949	48		1974	129211		1999	184679	
1950	30		1975	37899		2000	296579	
1951	89		1976	54154		2001	723733	
1952	81		1977	504992		2002	154219	
1953	69		1978	386793		2003	217734	
1954	62		1979	151591		2004	187369	
1955	138		1980	123380		2005	80663	
1956	673		1981	37875		2006	277568	
1957	366		1982	50013		2007	254426	
1958	173		1983	43433	33392	2008	169537	
1959	448		1984	54607	129726	2009	25912	
1960	281		1985	40717	46749	2010	300	
1961	174		1986	37006	12857	2011*	257241	
1962	666		1987	31588	14716	2012*	119335	
1963	1954		1988	72420	45656			

*preliminary

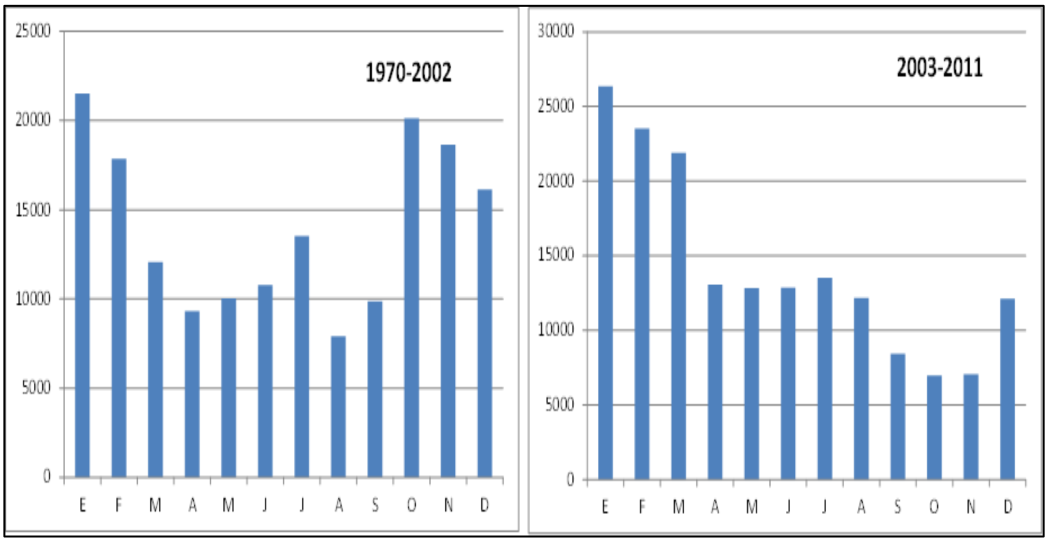

Figure 30. Seasonality of jack mackerel catches in Peru

4.3 Changes in spatial availability

The observed changes in latitude of the jack mackerel catch distributions seems to be clearly associated with increases in the speed and south-north direction of the Peruvian coastal current that is produced during and immediately after La Niña. Under these circumstances the availability of jack mackerel is higher and therefore the volume of catches increases. This phenomenon has been observed in several years and has been particularly strong in 2001, when the annual catch reached 775 thousand tons in Peru, and even Ecuador had high catches of 130 thousand that year (Fig. 31). Something similar was observed during 1995-96 and 2006-07, when environmental events such as La Niña took place (Trasmonte and Silva, 2008). As already mentioned, these latitudinal displacements of jack mackerel concentrations may be related to the intensity and duration of environmental changes in the Peruvian waters and/or in the whole southeastern Pacific (Ñiquén, 2010).

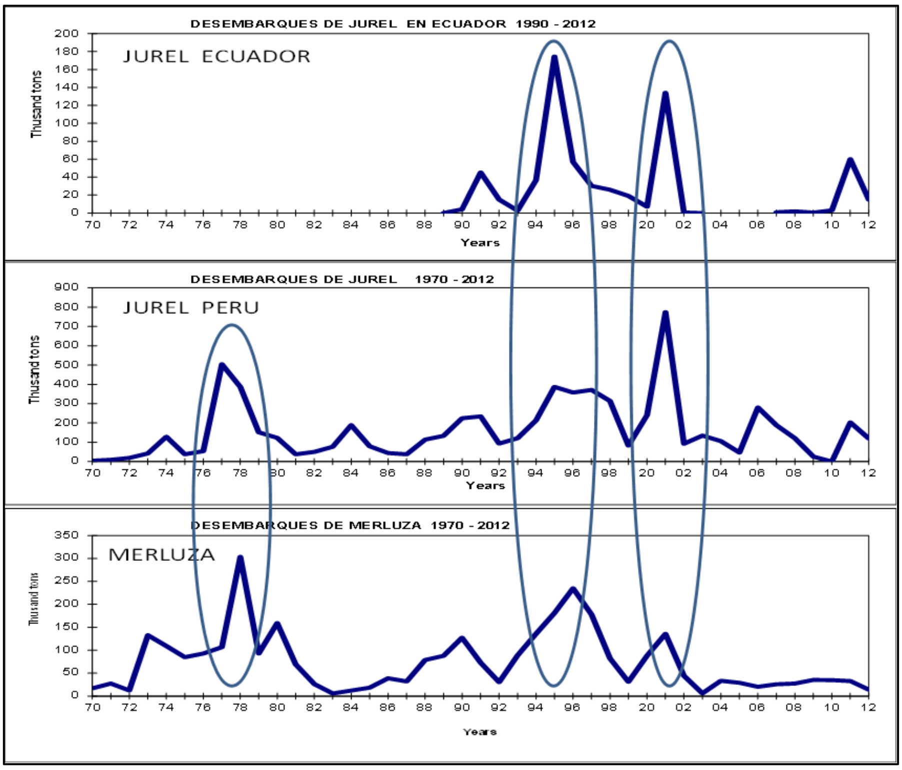

Figure 31. Landings of jack mackerel and hake in Peru and its association with landing of jack mackerel in Ecuador

5. STOCK ASSESSMENT METHODS

Fisheries monitoring

Peru has a monitoring system of the jack mackerel fishery that covers both the landing sites and the operations onboard fishing vessels. Relevant data are collected on a daily basis, including: catch volume, fishing effort, size structure of catches, species composition, discards, school characteristics, presence of sea birds and marine mammals and data on environmental variables, primarily surface temperatures. The geographic position of fishing vessels by satellite positioning system (SISESAT) is also registered.

Acoustic assessments

In addition to the fisheries monitoring, direct assessments are conducted through scientific surveys using the acoustic method. There are at least three scientific cruises a year: in summer (February-March), winter (August-September) and spring (November-December). Although the objective of these cruises is mainly the assessment of the anchoveta, other pelagic species are also assessed including jack mackerel. The study area covers the fisrt 100-120 miles from the coast along the whole Peruvian coast. Therefore these acoustic biomass estimates do not represent the total biomass of the stock of jack mackerel which is known to extend far offshore (250-300nm), and only represent the biomass of the portion in neritic part of its distribution which, as discussed above, may change due to changing environmental conditions.

Population balance

Because of the difficulty to assess the whole distribution area of this straddling stock, an operational model for jack mackerel biomass has been used, as follows:

$$B_t = B_d + B_{nd}\,;$$

Where B_t = total biomass, B_d = available biomass (estimated by the acoustic surveys) and B_{nd} = unavailable biomass (biomass outside the surveyed area).

The lack of information about what would be the magnitude of the biomass outside the surveyed area has led IMARPE to the decision of making regular catch projections, starting from the biomass estimates from the acoustic surveys (B_d) as a base, or as an indicator of the minimum stock size that would explain the catches and biomass estimates in preceding and successive months and years. .

The Population Balance is a monthly catch projection of the Thompson and Bell type (Thompson and Bell, 1934), that begins with the abundance and biomass estimated by a scientific survey. Calculations are made using the size frequency distributions from the scientific surveys (corresponding to the biomass being estimated) and from the commercial catches, as well as an exploitation pattern obtained from the relation between catch in numbers and biomass by size range of the previous months and/or years. The parameters of the von Bertalanffy growth function used are those estimated by IMARPE, where L_∞ = 80.77 cm total length, K = 0.1553 per year, t_o = -0.3562. The exploitation rates (E) commonly used for calculating advisable catch rates are below 0.35.

One major problem with this procedure is that the size frequency distributions estimated through the acoustic scientific surveys are not always representative of the population present in the surveyed area. That is because the fishing gear used by the research vessel (a modified pelagic trawl) is not appropriate for catching jack mackerel due to the avoidance and general behavior of the jack mackerel and the poor selectivity of the gear. To alleviate this problem, some intermediate procedures are used, such as:

a. project the last biomass estimate to the present (discounting the observed catches) to determine the level of bias in the estimated size frequency distribution of the stock;
b. make a backward projection from the most recent biomass estimate (t) to the next previous one (t-Δt), to have a more complete view of the size frequency distribution of the stock and make an estimation of what was not seen during the surveys (but may have been caught by the fleet);

c. use directly the size frequency distribution from the fishery, under the assumption that it would reflect better the size frequency distribution of the (exploited) stock;
d. join the size frequency distributions estimated by the acoustic surveys with those from the fishing fleet, when data was complementary;
e. a combination of two or more of the above.

In recent years the situation became more problematic due to the low availability of jack mackerel in the surveyed area, and the presumably much larger proportion of the non-surveyed (B_{nd}) portion of the stock in relation to the surveyed portion (B_d). However, in addition to the results of commercial catches, there have been numerous evidences of the presence of jack mackerel both outside the surveyed area as well as inside the surveyed area but not detected by the scientific acoustic surveys (probably due to a spatial mismatch or a too shallow distribution of the jack mackerel in the surveyed area). These evidences include visual and acoustic records from anchoveta fishing vessels, reports of jack mackerel as by-catch in industrial and artisanal catches, presence in stomach contents of other marine species such as jumbo squid, etc. Therefore, this increased level of uncertainty with the acoustic biomass estimates called for the use of an alternative model that would not depend that much on calculations of the population structure and better integrates existing historical information.

Biomass dynamic models

A biomass dynamic model (Hilborn and Walters, 1992) of the Schaefer type was implemented for jack mackerel since 2007, as an alternative way to assess the status of this stock and provide management advice. Time series of catch, standardized CPUE (catch/trip) and an index of the acoustic biomass between 2002 and 2011 were used.

The fishing effort used was the one known to be directed to jack mackerel. As noted above, since 2002 there is a dedicated fleet having jack mackerel as one of its main target species, while in the past the fleet targeted on jack mackerel only as a second choice to the more abundant and easier to catch anchoveta. Therefore, this makes it very difficult to allocate a reliable jack mackerel fishing effort prior to 2002. A jack mackerel CPUE series was thus calculated for 2002-2011, being expressed in terms of nominal and effective fishing effort (e. g. catch per fishing trip, catch per searching time, etc.). Standardization process included the use of Linear General Models.

6. SITUATION OF THE STOCK

Results of population balance

The input values and main results of the population balance method for the years 2000 to 2011 are shown in Fig. 32. The upper panel shows the series of acoustic biomass estimates of jack mackerel (red vertical bars) and the monthly cumulative catches (blue line) used as inputs for the population balance for each inter-survey period and each year. The lower panel (red bars) shows the estimated annual exploitation rates (E) for the same period, where the exploitation rates have been estimated as the ratio of the cumulative catch for one year between the average biomass for the same year as calculated through the population balance which, as explained above, would represent at worst an underestimation of the actual biomass of the stock.

On average, the calculated annual exploitation rate is 0,23 (23%) even if in some years it has exceeded 0,40. It is also clear that in the most recent years the exploitation rate has not been higher than 0,20, and it is noted that an exploitation rate of 0,20 to 0,23 is considered as a prudent conservative exploitation rate for a species such as jack mackerel. It is stressed that these calculations are based only on the available biomass estimated within the first 100 miles of the coast and, therefore, is likely to underestimate the total and mean biomass of the stock and consequently overestimate the exploitation rates calculated thereafter.

This means that the decrease in the availability of jack mackerel off Peru as estimated by the acoustic surveys in recent years is not due to overfishing, and is most likely caused by an environmentally driven decline in stock size, a reduced availability in the more coastal neritic areas, or a combination of both. There are some indications of possible effects of mid and longer term changes in environmental signals on the stock of jack mackerel but it is clear that this need to be investigated further before.

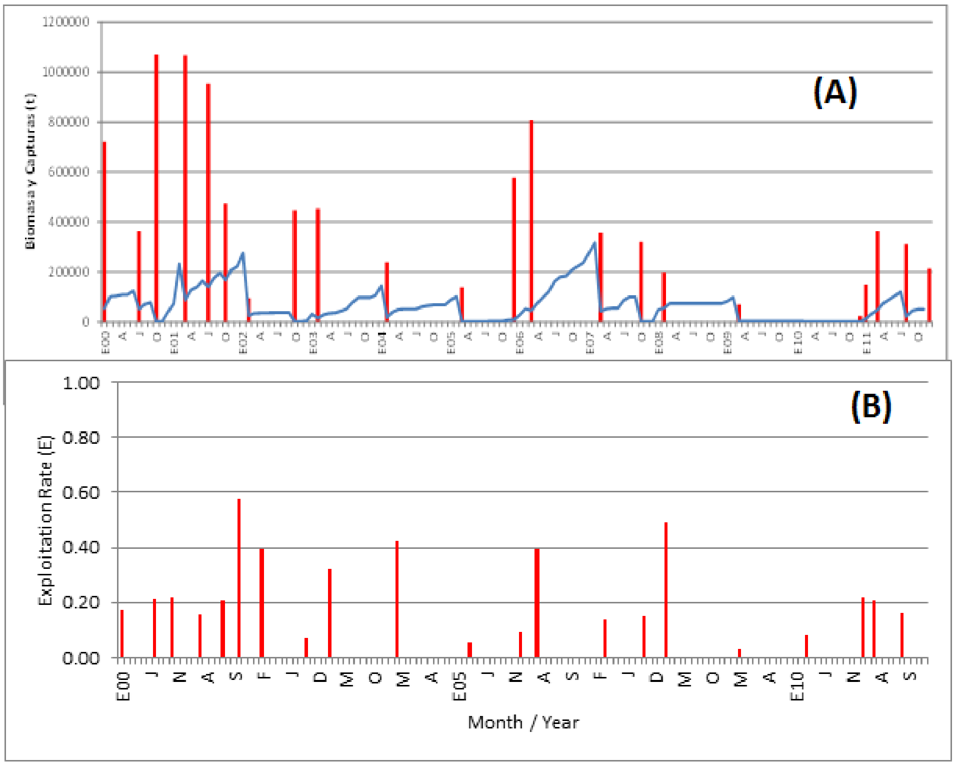

Figure 32. (A) Acoustic biomass of jack mackerel off Peru (red bar) and monthly cumulated catches (blue line). (B) Annual exploitation rate.

Results of the biomass dynamic model

The most recent assessment (period 2002 – 2011) using the biomass dynamic model shows that the jack mackerel biomass off Peru is about 850 thousand tons (±90 thousand tons) while the MSY has been estimated in 187 500 tons. According to this model, the estimated fishing mortality (F) applied to the stock has averaged 0,2 (±0,09) per year and the consequent exploitation rate (E) has fluctuated around 0,38 (±0,14) per year (Fig. 31). These results are not the same as, but are consistent with the results from the population balance and also estimate relatively low levels of fishing mortality and exploitation rates for the jack mackerel off Peru.

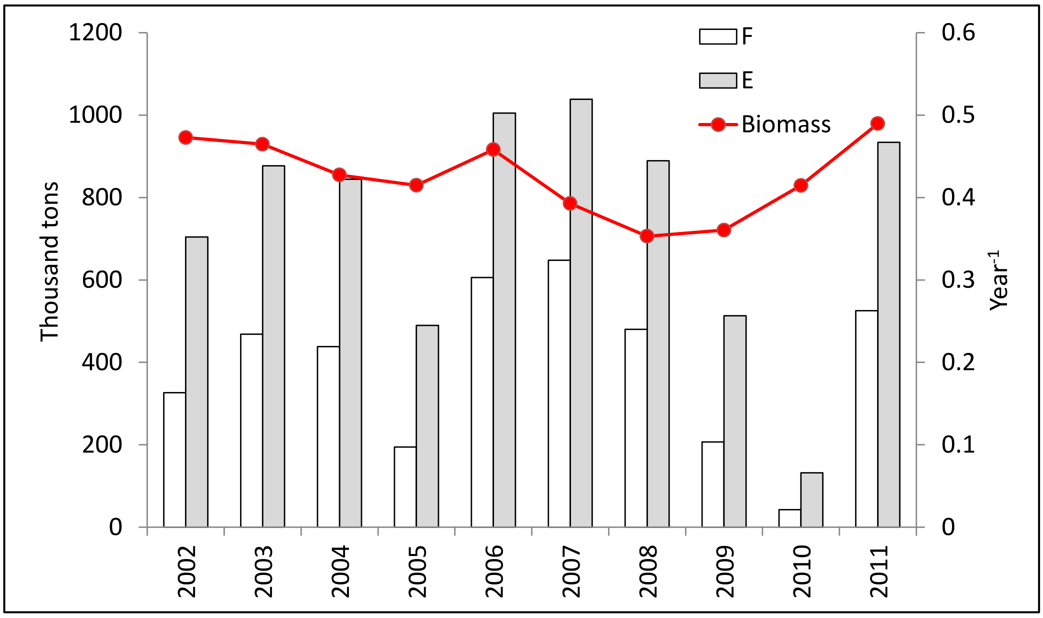

Figure 31. Biomass, fishing mortality (F) and exploitation rate (E) for the jack mackerel stock off Peru as estimated by the Biomass Dynamic Model, years 2002–2011.

8. FISHERIES CONSERVATION AND MANAGEMENT

Peru has adopted a legal and institutional framework for the establishment of fisheries conservation and management measures that is inspired in, and is fully in line with the guiding principles of the Code of Conduct for Responsible Fisheries (FAO, 1995). The Peruvian fisheries legislation has different hierarchy of laws and bylaws that guide the long term development of the Peruvian fisheries and that rule and oversee the more shorter term actions and as needed the day to day activities of the fisheries sector. The overall guidance is provided by the general principles for the sustainable use of the Peruvian natural resources contained in the National Act for the Sustainable Use of Natural Resources (Ley Orgánica para el Aprovechamiento Sostenible de los Recursos Naturales) and in the Peruvian General Fisheries Act (Ley General de Pesca). All fisheries conservation and management laws, bylaws and more specific regulations are based on the best and most up to date knowledge available and are aimed at satisfying shorter terms needs while guaranteeing the long term sustainability of the fishery resources and fisheries involved. The main objectives of the Peruvian General Fisheries Act are to promote the sustainable development of the Peruvian fisheries as a source of food, income and employment while ensuring that the aquatic living resources are exploited in a responsible manner, optimizing socio-economic returns in full harmony with environmental and biodiversity conservation concerns.

In establishing rules and regulations for each main Peruvian fishery through fisheries management laws and bylaws (the 'Reglamentos de Ordenamiento Pesquero', ROP) due account is taken of FAO's guidelines in this respect, that defines fisheries management as *"The integrated process of information gathering, analysis, planning, consultation, decision-making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulations or rules which govern fisheries activities in order to ensure the continued productivity of the resources and accomplishment of other fisheries objectives"* (FAO, 1997). It is on this basis that the Peruvian General Fisheries Act establishes that *"the fisheries management schemes, including the setting of allowable catch quotas, fishing seasons, fishing areas, fishing effort, fishing methods, minimum size at capture and other regulations that may be required for the conservation and rational exploitation of the aquatic living resources will be established, for each type of fishery, on the basis of the available scientific evidences and prevailing socioeconomic factors"*.

With respect to specific fisheries management regulations for jack mackerel during the last 30+ years, it is noted that in 1974 some legislation was introduced to set the minimum mesh size of purse seines fishing for jack mackerel in 38mm, with a minimum total length size at capture of 64cm for this species. In the 1980s there were two fleets being allowed to fish for jack mackerel off Peru: a purse seine fleet and a trawl factory fleet. Since jack mackerel was considered as underexploited in those days, the fleet fishing for this species was subject to a rather limited number of regulations and constrains. However, this changed as the fishing pressure on the jack mackerel increased and, for instance, starting in 1992 the purse seine fleet and other industrial fleets were banned from fishing in a coastal protected area measured from the 0 to the 5 nm from the coastline, which was reserved for the artisanal fishery.

Since 1984 the trawl factory fishery was managed according to the ruling of a Supreme Decree 0122-84 PE that established that the then Peruvian Ministry of Fisheries should carry out the control of the fishing licenses of these fleets, concealing the fishing effort with the allowable catches recommended by IMARPE. This same Decree reserved for the State 25% of the total annual allowable catch of jack mackerel, chub mackerel and hake and other species, which could be exploited through ad-hoc agreements with national or foreign entrepreneurs and ship owners. It also established a minimum mesh size limit of 76mm in the cod end of the trawl nets, restricting their fishing grounds to areas away from the coastal zone, to areas with bottom depths of at least 100 meters and at least a 20 nm distance away from the coast (modified to 30 nm in 1990).

At present, and according to the principles of the General Fisheries Law (Decreto Ley Nº 25977), the fisheries activities are to be managed promoting their sustainable development and ensuring a responsible use of the living aquatic resources in harmony with the preservation of the environment and conservation of the biodiversity. And the various fisheries are managed through fisheries regulations and bylaws (approved through Supreme Decrees) which tend to be specific for each type of fishery, the state of exploitation of the target stock(s) and are based on the most updated knowledge about the biologic, operational, economic and social components of each fishery.

In the case of the jack mackerel (*Trachurus murphyi*) the regulation currently in force (Supreme Decree Nº 011-2007-PRODUCE), establishes a restricted access regime limited only to vessels with operative onboard cooling systems devoted to properly store and preserve their catch which could only be used for direct human consumption. This regulation that limits the capture and use of jack mackerel exclusively for direct human consumption has been in force during the last eleven years and has been fully complied with, within the framework of a specific bylaw for the management of the jack mackerel and chub mackerel fishery.

In the case of the purse seine fleet, the entrance of new vessels to the fishery is only authorized if it replaces the same hold capacity of an already existing vessel with a valid fishing license for jack mackerel that will be decommissioned transferring its fishing license to the new vessel. The boat owners of vessels authorized to fish for jack mackerel and chub mackerel pay a license fee and the vessels can only fish beyond the 10 miles from the coast. Trawl fishing vessels can only operate at bottom depths greater than 200 meters.

The current regulations establish a minimum mesh size for fishing for jack mackerel of 38 mm (1 ½ inch) for the purse seine nets and 76 mm (3 inches) in the codend for the middle water trawl nets. It is also prohibited to catch, process and market jack mackerels smaller than 31 cm total length and chub mackerels smaller than 29 cm fork length (equivalent to 32 cm total length). Special regulations (Ministerial Resolutions) establish and modify closed seasons, fishing seasons and the corresponding catch quota limits, as well the specific monitoring, control and surveillance actions that may be required. Some of the most recent regulations for the conservation of jack mackerel and chub mackerel issued during the period 2010-2012 are listed below:

- RM N° 026-2010-PRODUCE, in force since 02/03/2010, establishing a Provisional Regime for the extraction of the JACK MACKEREL and CHUB MACKEREL in all the Peruvian littoral, until March 31, 2010, applicable to the catches from the artisanal fishery and larger fishing vessels with valid license to fish of such resources.
- RM N° 027-2010-PRODUCE, in force since 02/03/2010, establishing an Exploratory Fisheries Regime for PELAGIC resources associated to El Niño event in all the Peruvian littoral, which authorizes the extraction of resources such as EASTERN PACIFIC BONITO, SKIPJACK TUNA, FRIGATE TUNA, JACK MACKEREL and CHUB MACKEREL and others until May 31, 2010.
- RM N° 096-2010-PRODUCE, in force since 17/04/2010. Establishes a Provisional Regime form the extraction of the resources JACK MACKEREL and CHUB MACKEREL, in all the Peruvian littoral, since the date of publication up to the 31st May 2010, applicable to the catches from the artisanal fishery from larger fishing vessels with valid fishing

licenses. Establishes a monthly catch limit of 15,000 metric tons. Once the limit for each species is reached the Production Ministry will suspend the extraction activities for the days left in the corresponding month. The extraction activities, will be subjected to the fulfilling of the regulations held in Supreme Decree N° 011-2007-PRODUCE 13/04/2007.

- RM N° 097-2010-PRODUCE, in force since 18/04/2010, establishes an Exploratory Fishery regime for opportunity PELAGIC resources associated to El Niño event in all the Peruvian littoral, and authorizes the extraction of the resources of EASTERN PACIFIC BONITO, SKIPJACK TUNA, FRIGATE TUNA, JACK MACKEREL and CHUB MACKEREL and others until May 31 2010. It prohibits the extraction, reception and processing of ANCHOVETA and HAKE including its accompanying fauna.
- RM N° 202-2010-PRODUCE, in force since 18/08/2010. Establishes a Provisional Regime for the extraction of the resources JACK MACKEREL and CHUB MACKEREL in all the Peruvian littoral, for a term of sixty (60) calendar days starting on the date of publication, covering the captures coming from the artisanal fishery and from larger fishing vessels with valid fishing licenses for these resources.
- RM N° 035-2011-PRODUCE, in force since 06/02/2011. Suspends from the 00:00hrs of the 7th of February and until 24:00 hrs of February 28th 2011, the extraction and reception activities of jack mackerel within the framework of the Provisional Extraction Regime established by Ministerial Resolution N° 025-2011-PRODUCE.
- RM N° 038-2011-PRODUCE, in force since 09/02/2011. Modifies articles 1º and 2º of the Ministerial Resolution 035-2011-PRODUCE of 06/02/2011 with the following text: "Article 1°,=- Suspend, starting at 00:00 hours of the 7th of February until 24:00 hours of February 28th 2011, the extraction activities of the resource JACK MACKEREL within the Provisional Extraction Regime, established by Ministerial Resolution N° 025-2011-PRODUCE. Article 2 °.- The processing activity of the Jack mackerel resource may be developed until the 24:00hrs of the 9th of February”.

- RM N° 058-2011-PRODUCE, in force from 26/02/2011. Modifies the first paragraph of article 2º of the Ministerial Resolution Nº 025-2011-PRODUCE, determining that the catch limit established is to be applied to the catches made by the larger fishing vessels until the conclusion of the Provisional Extraction Regime of the JACK MACKEREL and CHUB MACKEREL; extending the limit of the catches to forty five thousand (45,000) metric tons. It states that from the catch limit established in the present Provisional Extraction Regime, applicable to the larger vessels, there are twenty five thousand two hundred thirty six (25,236) metric tons of JACK MACKEREL to be extracted.
- RM N° 099-2011-PRODUCE, in force since 20/03/2011. Suspends starting at the 00:00hours of the following day the extraction activities of the resource JACK MACKEREL allowed by the Ministerial Resolution N° 058-2011-PRODUCE.
- RM N° 107-2011-PRODUCE. In force since 25/03/2011. Extends until the 30th of April 201, in all the Peruvian littoral, the enforcing of the Provisional Fishing Regime for JACK MACKEREL and CHUB MACKEREL established by Ministerial Resolution N° 025-2011-PRODUCE and extends the catch limit applicable to the larger fishing vessels up to fifty five thousand (55,000) metric tons of the jack mackerel and chub mackerel respectively.
- RM N° 124-2011-PRODUCE, in force since 10/04/2011. Suspends starting the 00:00 hours of the following day the extraction activities of the JACK MACKEREL within the framework of the Provisional Extraction Regime, established by the Ministerial Resolution Nº 025-2011-PRODUCE, modified by Ministerial Resolution N° 058-2011-PRODUCE and prorogated by Ministerial Resolution 107-2011-PRODUCE.
- RM N° 130-2011-PRODUCE, iin force since 13/04/2011. Extends the catch limit of the larger fishing vessels to up to sixty two thousand (62,000) metric tons for JACK MACKEREL, within the frame of the dispositions of the Provisional Regime established by Ministerial Resolution N° 025-2011-PRODUCE.

- RM N° 146-2011-PRODUCE, in force since 28/04/2011. Prorogates until the 30th of June 2011 in all the Peruvian littoral, the effect of the Provisional Extraction Regime for the JACK MACKEREL and CHUB MACKEREL established by Ministerial Resolution N° 025-2011-PRODUCE.
- RM N° 198-2011-PRODUCE, in force since 29/06/2011. Establishes a catch limit of forty five thousand (45,000) metric tons for JACK MACKEREL and CHUB MACKEREL respectively, starting on the 00:00 hours of the 1st of July and until the 24:00 hours of September 30, 2011 in all the Peruvian littoral.
- RM N° 277-2011-PRODUCE, in force since 01/10/2011. Extends the catch limit of JACK MACKEREL and CHUB MACKEREL established by Ministerial Resolution N° 198-2011-PRODUCE, to up to seventy five thousand (75,000) metric tons respectively since the following day and until the 24:00 hours of the 31st of December 2011, in all the Peruvian littoral.
- RM N° 034-2012-PRODUCE, in force since 24/01/2012. Establishes the catch limit for JACK MACKEREL and CHUB MACKEREL in forty thousand (40,000) and twenty thousand (20,000) metric tons respectively, for the first trimester of 2012.
- RM N° 055-2012-PRODUCE, in force since 03/02/2012. Suspends extraction activities of JACK MACKEREL starting 00:00 hours of the following day in all the Peruvian littoral. The vessels that were still fishing will have two (2) calendar days for landing.
- RM Nº 132-2012-PRODUCE, in force since 22/03/2012. Specifies the scope of the Ministerial Resolution RM Nº 0334-2012-PRODUCE clarifying that the catch limit for JACK MACKEREL and CHUB MACKEREL corresponding to the first trimester of 2012, are stated for the extraction activities performed by the industrial fishing fleet. According to this the suspension of the extraction activities of JACK MACKEREL resource as established by the Ministerial Resolution RM Nº 055-2012-PRODUCE are not apply to the artisanal fleet .

- RM N° 133-2012-PRODUCE, in force since 23/03/2012. Established the catch limit for JACK MACKEREL and CHUB MACKEREL in 30 thousand and 20 thousand metric tons respectively for the extraction activities performed by the industrial fishing fleet corresponding to the second trimester of the year 2012, between the 1st of April and the 30th of June 2012. Once the capture limit is accomplished for each species, the Production Ministry will suspend the extraction activities for the days left in the authorized period. RM N° 142-2012-PRODUCE, in force since 24/03/2012. Modifies article 1º of the Ministerial Resolution N° 133-2012-PRODUCE 23/03/2012, JACK MACKEREL AND CHUB MACKEREL.
- RM N° 173-2012-PRODUCE, in force since 15/05/2012. Establishes the total allowable catch of JACK MACKEREL for the year 2012 in one hundred twenty thousand (120,000) metric tons. The established quota includes the catches performed under Ministerial Resolution N° 034-2012-PRODUCE, stated by Ministerial Resolution N° 142-2012-PRODUCE.
- RM N° 191-2012-PRODUCE, in force since 19/04/2012. Suspends the extraction activities of JACK MACKEREL starting at the 00:00 hours of the 21st of April 2012, in all the Peruvian littoral, therefore the transport and marketing of the stated resource is prohibited starting in 4 calendar days. The ship owners of industrial vessels fishing vessels capturing JACK MACKEREL in the Peruvian littoral at the time will have two (2) calendar days to proceed with the landing of their catches.

An effective fisheries management legal and institutional framework requires that effective measures be applied for the monitoring, control, surveillance and enforcement including, where appropriate, observer programs, inspection schemes and surveillance systems. In the case of Peru, the Ministry of Production is the Governmental institution that has the responsibility for managing the rational exploitation of the national living aquatic resources, including the monitoring and control of all fishing operations within Peruvian waters, and beyond for longer range Peruvian fleets. This at present includes the monitoring and control of fishing vessels through the use of appropriate satellite surveillance systems and observers on board. All this in addition to the traditional monitoring and control systems at the landing sites, which provides for a more effective compliance with catch quotas and other fisheries regulations. As with other species, in the case of jack mackerel, total allowable catches and other fisheries regulations are set on the basis of the assessments and other biological and fisheries studies conducted by IMARPE, which are then enforced, monitored and controlled by the Ministry of Production.

An historical account of the total allowable quotas that have been set in Peru for the capture of jack mackerel from 1982 throughout 2011 is provided in Table 9. The same Table includes a reference to the legal law or bylaw that established the quota and the actual catch and a reference to the obtained in each year. One thing to emphase here is that for several years the actual Peruvian catches of jack mackerel were well below the authorized allowable catch quotas.

Table 9. Allowable catch quotas and actual catches of jack mackerel per year, Peru, 1982-2011

Year	Period	Jack Mackerel		Legal statement
		Quota (Thousan tons)	Catch (Thousan tons)	
1982	JAN - DEC	1000	50,013	
1983	JAN - DEC	2700	76,825	
1984	JAN - DEC	2300	184,333	
1985	JAN - DEC	2000	87,466	
1986	JUN - SEP	--	15,558	R.M.163-86-PE
	OCT - DEC	--	5,291	R.M.284-86-PE
1987	JAN - APR	1000	5,685	R.M. 033-87-PE
	OCT - DEC	2500	13,553	R.M. 323-87-PE
1988	JAN - MAR	1000	26,854	R.M. 007-88-PE
	OCT - DEC	--		R.M.317-88-PE
1989	NOV - DEC	--		R.M.431-89-PE
1990	JAN - AUG	1300	39,772	R.M. 084-90-PE
	SEP - DEC	--		R.M. 525-90-PE
1991	JAN - MAR	400	9,763	R.M. 029-91-PE
	APR - JUL	1800	45,600	
1992	JAN - DEC		96,660	
1993	JAN - DEC		130,681	
1994 - Nov 2005		WITHOUT QUOTA		
14-dic-05	Ban 15 days since 16 december	Close season		R.M. 339-2005-PRODUCE
16-dic-05	Ban 15 days since 19 december	Ban & start Exploratory Fishery		R.M. 347-2005-PRODUCE
2006	19 jan - 31 March	Provisional Regimen of jack mackerel, without quota	94,978	R.M. 015-2006-PRODUCE
	03 april - 30 june	Provisional Regimen of jack mackerel, without quota /whereas = 60 thous tons	68,569	R.M. 090-2006-PRODUCE
	08 july - 31 august	Provisional Regimen of jack mackerel, without quota /whereas = 60-80 thous tons	43,273	R.M. 173-2006-PRODUCE
	28 dec 2006 - 31 jan 2007	Provisional Regimen of jack mackerel, without quota, only mention that juvenile catch will be no more than 20 thousand tons	33,694	R.M. 358-2006-PRODUCE
2007	Feb - 30 April	extends RM 358-2006 in same terms	73,614	R.M. 030-2007-PRODUCE
	28 JUL - 30 SEP	40 (20/month)	28,562	R.M. 237-2007-PRODUCE
	21 OCT - 31 DEC	40 (20/month)	30,046	R.M. 310-2007-PRODUCE
				R.M. 318-2008-PRODUCE
2008	16 FEB - 31 MAR	76 (38/month)	83,735	R.M. 355-2008-PRODUCE
2009	18 JAN - 31MAR	60 (20/month)	36,279	R.M. 208-2009PRODUCE
2010	February – March	30 (15/month)	0,976	R.M. 026-2010-PRODUCE
	April – May	30 (15/month)	1,951	R.M. 096-2010-PRODUCE
	18 august-18 october	30 (15/month)	3,555	R.M. 202-2010-PRODUCE
2011	27 january – 30 june	120	117,693	R.M. 025/O58/107/146-2011 PRODUCE
	01 july-30 december	75	80,946	R.M. 198/277-2011-PRODUCE

Data subject to adjustment

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