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Characteristics of the Peruvian Stock

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CHARACTERISTICS OF THE PERUVIAN STOCK (NORTHERN STOCK) OF JACK MACKEREL (*Trachurus murphyi*) IN THE SOUTHEAST PACIFIC AND NOTES ON THE SCIENTIFIC BASIS FOR ITS DIFFERENTIATION

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1. Introduction

Fisheries management requires the identification of a stock unit, on the basis of which fishing effort is allocated, the type of fishery is categorized, monitoring and assessment systems are developed and the biological reference points are identified (Gulland, 1971; Hilborn & Walters, 1992, Abaunza, 2008).

Since the beginning of the negotiations for the establishment of the South Pacific Regional Fisheries Management Organization (SPRFMO) Peru, on the basis of the scientific information collected through its fishery resources monitoring programs, has sustained the existence of a distinct jack mackerel stock unit adapted to the specific characteristics of Peruvian waters. The current Peruvian national fisheries management regime (ref.: Supreme Decree N°011-2007-PRODUCE and other related regulations available in the web, at www.produce.gob.pe) is based on this assertion, i.e. that the jack mackerel is a typical species of the Peruvian upwelling ecosystem and that there is a straddling stock that has its distribution area and completes its life cycle both within the national jurisdictional waters as well as in the adjacent high seas.

In recognizing the need to look further into the matter of the jack mackerel stock structure and to work on the development of viable working stock structure hypotheses upon which to base future stock assessments of the jack mackerel in the area, the discussions in the SPRFMO focused almost exclusively on the development of working hypothesis about the stock structure for use in the assessments of jack mackerel stocks in the area. Upon reviewing all the available evidence to date, it was proposed four main working hypotheses: two alternative working hypothesis regarding the Peruvian and Chilean stocks and two more regarding the jack mackerel caught off central-southern Chile from the coast out to about 120^{0}W.

Among these, the first hypothesis (the main one from our point of view and the one supported in this report) is the one stating that “jack mackerel caught off the coasts of Peru and Chile each constitute separate stocks which straddle the high seas”. A fairly substantial amount of historic and current evidence supporting these four hypotheses was summarized while addressing some very important questions, such as: What is the evidence for separate ‘Peruvian’ and ‘Chilean’ jack mackerel stocks, and where would the most likely division be between such stocks?

In the framework of these discussions, Gerlotto et al. (2010), while assuming genetic homogeneity in the entire region, made a comparison among the characteristics of the jack mackerel distribution in the south Pacific with the attributes of a superpopulation and of a metapopulation. In simple terms, the concept of metapopulation, introduced by Levins (1969), means a population of populations, while a superpopulation refers to a panmictic population in a large space. The main conclusion of this study was that the concept of metapopulation was the most appropriate model to explain the population structure of jack mackerel in the south Pacific. However, they did recognize the difficulty of applying this concept to pelagic gregarious species such as jack mackerel, because the concept of metapopulations theory has been developed mainly for species living in a highly fragmented environment (Hanski, 2004), which is not exactly the case of jack mackerel. For that reason there are some critics to the utility of the metapopulation model for the purpose of resource conservation (Baguette, 2004). In a more recent research work (Gerlotto et al, in press) examine further some particular spatial characteristics observed recently between the Peruvian and the central-south Chilean parts of the jack mackerel distribution and also conclude that the metapopulation is likely to better describe the population structure of the jack mackerel in the South Pacific, providing insights into some of the implications for fisheries management purposes under this population structure concept. It is noted that this proposal of a metapopulation is not entirely incompatible with Hypothesis 1 (separate stock units off Peru and off Chile) mentioned above and to be explained and discussed further in this report.

The work of Elizarov et al (1993) provides the basic framework for most of our present knowledge on the jack mackerel distribution in the South Pacific. They coined the concept of “the jack mackerel belt” to explain the spatial distribution and possible migratory routes of this species in the region. Their work was based on data collected during three decades, between the 1970s and 1990s off Peru and Chile. They hypothesized that adult jack mackerel is distributed westward mainly due to the “the lack of food for older specimens” in the offshore zones adjacent to the continental shelves of Peru and Chile. In their study there is no major discussion of the possible migratory mechanisms of jack mackerel between Peru and Chile other than pointing out than suggesting that the area off Peru would be a spawning area from where the spawning products would be transported westward by the superficial currents and southward, off Chile, by the Peru-Chile Countercurrent.

This report being presented to the SPRFMO 11th SWG and 10th D&IWG meetings (Lima, Peru, 15-19 October 2012), examines the available scientific evidence about the existence of a stock unit of jack mackerel in the Peruvian sea and the adjacent high seas, and updates some of the available observations and results already reviewed within the context of the SPRFMO. In so doing, this report presents an integrated review of the main characteristics of this stock based on information and data collected for more than 40 years and that in our view provides strong evidence in support of the Peruvian stock unit concept and the application of this concept in the management of the Peruvian fisheries targeting on jack mackerel for so many years. No attempts to deal with the important issue of stock abundance variability in relation to the environmental variability at different time scales within the SE Pacific which is dealt in another report being presented by Peru in this same meeting.

2. On the “stock unit” concept and the integrated approach

Several definitions have been proposed with time about the concept of “stock unit”. These definitions range from those having an operational approach based on the fishery perspective (part of a population affected by the fishery with effects on the whole population) to a more idealized approach based on the point of view of conservation biology (naturally defined linages within the species), Waldman (2005). Even when there is no consensus on the concept of stock unit, it is clear that in the hierarchy of biological classification, this structure (the stock) is below or has as top limit, the species level.

The difficulty to achieve consensus regarding the definition of stock unit has made it also very difficult to establish a single process to identify stocks, which at present is mostly dependent on the analyses of the characteristics of the stock or stocks in question and their possible differences or uniqueness, if any. Taking into account these difficulties, Begg & Waldman, (1999) suggest a more holistic approach to the identification of a stock unit, i.e. though the combination of results obtained with different techniques of identification.

However, from the fisheries management perspective, what is required is that the group of fish subject to a fishery (and to a common management regime) needs to have at least two main attributes: individuals must be able to reproduce amongst themselves, and must have similar life history characteristics (Hilborn and Walters, 1992). Thus both the quantification of fishing mortality and the effect of management measures acts on homogeneous elements. Therefore, understanding the life cycle characteristics of an exploited resource is the first fundamental step to identify stocks units, and this should be done even before attempting more specific stock identification analyses (Pawson and Jennings, 1996; Begg et al.1999; Begg, 2005, in Abaunza, et al., 2008). A major attempt should therefore be made to examine the differential attributes of the jack mackerel stock living in the Peruvian and adjacent open sea, as a fundamental step in the process of identification of the possible different stocks of the jack mackerel species of the South Pacific.

3. Characteristics of the Peruvian stock of jack mackerel

3.1 Differential characteristics of the Peruvian sea (habitat)

One of the main factors influencing the process of biological adaptation of living species is the environment and how their habitat is affected by changing environmental conditions. As stated by Begon (1996) organisms are not randomly distributed in different environments, because there is a close relationship between the living beings and its environment.

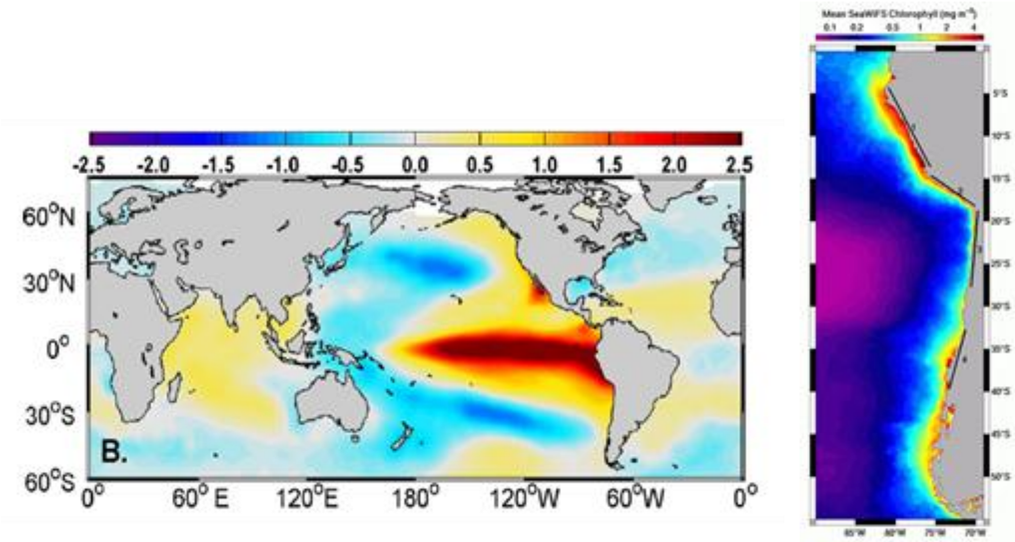

Figure 1. Left: Spatial pattern showing the variation of Sea Surface Temperature in terms of analysis of Empirical Orthogonal Functions (Chavez, et al. 2008); Right: Mean Primary Production along the western coast of South America (F. Chavez, unpublished data, based on Thomas et al, 2001).

In this respect, it is well known that the Peruvian sea has unique characteristics, hard to find in other parts of the world even if it is part of a large ecosystem internationally known as the Humboldt Current Large Marine Ecosystem. While there are common features at the level of the whole Pacific Ocean basin (Messié and Chavez, 2011), there are also some main differential features that are almost unique to the Peruvian sea, such as the high variability (e.g., in SST) and high productivity (Chavez et al., 2008), which are probably the highest in the planet (Fig.

1). An idea of the high variability in this area dominated by temperate conditions even if located at tropical latitudes is given by the sea surface temperature which can vary by as much as 11°C in a period of a few weeks, as occurred during El Niño 1982-83. In this respect it is worth noting that the jack mackerel seems to be well adapted to the dynamics of the water masses off Peru, particularly to those that form the oceanic front by the encounter of Cold Coastal Waters and Surface Subtropical Waters.

3.2 Morphometric and meristic characteristics

Table 1. Comparison of Trachurus murphyi characteristics (Nichols, 1920), Peru and Chile.

CHARACTER		7 specimens of PERU Hildebrant S. 1946 Standard length (mm): 485 - 497	1 specimen of PERU Miyahara H. 2009 Fork length (mm): 356	10 specimens of CHILE Nakamura I. 1986 Standard length (mm): 294.4 - 381.6
COUNTS:				
Dorsal fin		30 - 33	VIII - I, 34	VIII - I, 31 - 35
Anal fin		25 -27	II - I, 28	II - I, 27 - 29
Pectoral fin		---	22	22 - 24
Pelvic fin		---	I, 5	I, 5
Gill rakers	Upper limb	15 - 17	15	16-18
	Central	---	---	1
	lower limb	45 - 48	46	41-45
	Total	---	61	58-63
Lateral line scales (LLS)		93 -104	98	96-112

Morphometric and meristic characteristics have been considered historically as a basis for stock identification, since they are controlled genetically and environmentally, although it has been noted that environmental pressure only acts at the initial stages (Begg and Waldman, 1999). This is a subject matter area that still needs to be investigated in jack mackerel in Peruvian waters. For the time being, there is very littleinformation in the scientific literature, mostly based on few samples of adult specimens collected in different places, at different times and by different authors off Peru and Chile (Hildebrandt, 1946; Nakamura, 1986; and Miyahara, 2009). The information on morphometric and meristic characteristics shown in Table 1 show only slight variations that are not conclusive for the purposes of stock identification.

3.3 Genetic studies

Genetic differentiation is the basis for determining the level of reproductive isolation between species and also among stocks, when the isolation time has been sufficiently long to be reflected in the differentiation of selected genetic markers. When divergences are recent or are in process or (as is the case of the jack mackerel in this region) the potential barriers are altered by aperiodic but recurrent natural events such as El Niño, the results of this type of studies could result in the non-existence of differences, even when they exist (Begg & Waldman, 1999).

There are no genetic studies on jack mackerel of Peru, even if some studies have been conducted on other species of the Peruvian sea such as in hake (*Merluccius gayi peruanus*) and scallops (*Argopecten purpuratus*). However, the Instituto del Mar del Peru (IMARPE) has been collaborating with the Instituto de Fomento Pesquero de Chile (IFOP) to develop such type of analyses, within the framework of a holistic approach to identify stock units.

3.4 Life cycle parameters

3.4.1 Growth

Individual growth parameters for jack mackerel have been estimated based on otolith rings interpretation and corroborated with studies with fins and scales. Growth parameters of the von Bertalanffy function currently in use are: L_∞ = 80.77 cm total length; K= 0.1553 per year; t_0 = -0.3562. These estimates have been recently corroborated trough the analysis of long time series of size frequencies (1970 – 2011) and readings of daily increments observed in otoliths.

The above growth parameters for jack mackerel off Peru are compared (Fig. 2) with those estimated for the same species off Chile (Gili, 1995), resulting in a clear difference in growth rates and as consequence in longevity of jack mackerel caught off Peru and those caught off Chile. The higher growth rate (K) of Jack mackerel in Peru can be interpreted as an adaptive response of this species to the different thermal, nutrition rich and highly variable conditions off Peru.

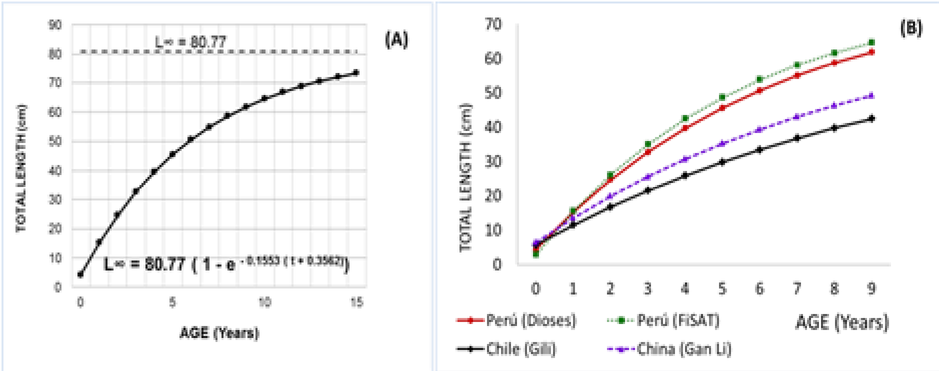

Figure 2. (A) Growth curve of Peruvian Jack mackerel. (B) Comparison of growth curves of Peruvian jack mackerel (broken green and continuous red lines), Chilean jack mackerel (bottom black continuous line) and jack mackerel in open ocean (purple broken line).

3.4.2 Natural mortality

Based on the growth parameters of the von Bertalanffy growth function and other traits of the jack mackerel life cycle off Peru, alternative methods to estimate natural mortality (M) has been used, resulting in an average estimation of M=0.31 year^{-1} (Table 2). Again, this is a much higher natural mortality than that estimated for the Chilean jack mackerel stock (M = 0.23 per year (Canales y Serra, 2008).

Table 2. Estimations of natural mortality (M) for Peruvian jack mackerel stock by four methods.

Method	M (year)
M (Pauly)	0.33
M (Jensen)	0.23
M (Froese)	0.36
M (Hoenig)	0.31
M average	**0.31**

3.4.3 Size at first maturity

Time series of mean size at first maturity for jack mackerel caught off Peru and off Chile (1963-2011) are shown in Fig. 3. To facilitate the comparison fish lengths have been standardized to total length using the relationship between total length and fork length available in the database Fishbase (www.fishbase.org).

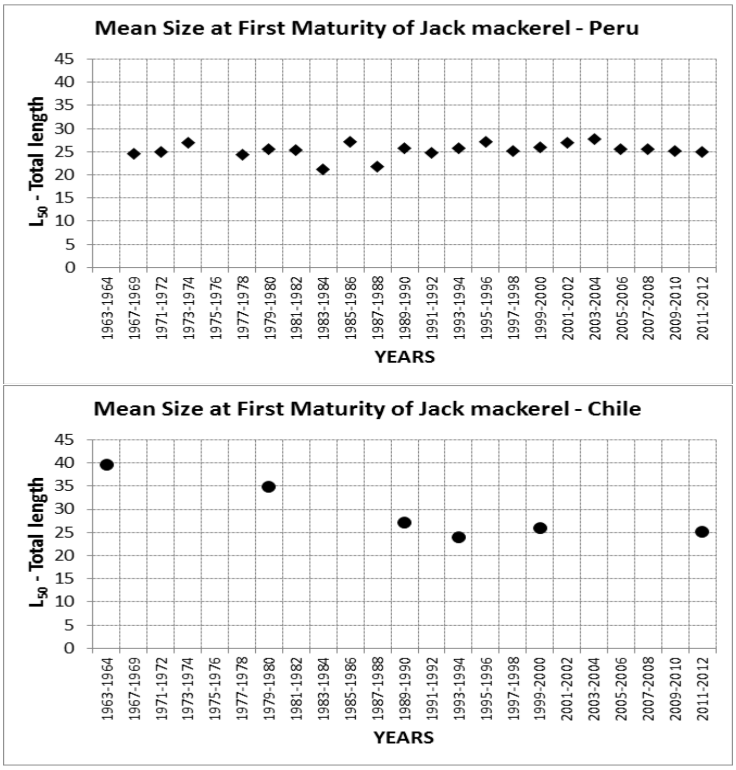

Figure 3. Comparison of size variations in the total length at first maturity between jack mackerel distributed off Peru and off Chile (1963-2011)

The source of information for the jack mackerel off Chile has been taken from a recent review by Cubillos (2008), while for the Peruvian case the data source is the pelagic fisheries monitoring program of IMARPE since 1967 to 2011. Data was recently compiled and analyzed, calculating the size at first maturity by adjusting a logistic function, according to the internal protocol adopted by IMARPE (Buitrón et al, 2011, in press).

The mean size at maturity of jack mackerel off Peru does not present any trend and clearly shows a notable stability. However in the jack mackerel off Chile there is a clear declining trend that has been described and commented by Arancibia (2010) as a process of neoteny.

This represents an evidence of the independence of the jack mackerel life cycle off Peru with respect to other stocks in the south Pacific. The jack mackerel off Peru shows an early maturity that has remained relatively constant from the very early times of the fishery, when the fishing pressure was very small to almost negligible as compared to latter catch rates. This earlier size (and age) at first maturity may be the result of a long term local adaptive response of the Peruvian jack mackerel stock to environmental characteristics and variability of its habitat.

3.4.4 Spawning cycle (seasonality)

The Gonadosomatic Index (GSI) is a reliable gravimetric method which objectively shows the growth in weight of the ovary products and can be monitored as indicator of spawning process, and this is the method being used by to describe the reproductive cycle of jack mackerel.

The available data and information (gathered though the ongoing pelagic fisheries follow up programs in Chile and Peru) was grouped according to main landing sites into two zones covering the extremes of the whole latitudinal distribution of the species, one for Peru (most northern distribution) and one for Chile (central and most southern distribution), as follows:

1. Peru (ports of Paita to Ilo).
2. Central - South of Chile (ports of San Antonio to Guaiteca)

Differences were found in each zone based on: amplitude of each reproductive time-cycle, timing/month of maximum reproductive activity and variability during the month with maximum reproduction.

Month of maximum spawning activity

For the jack mackerel off central – south Chile, there is a difference regarding the timing (month) of maximum reproductive activity. The maximum GSI values are observed in December while in the case of the jack mackerel off Peru, the maximum reproductive activity is in November (Fig. 4).

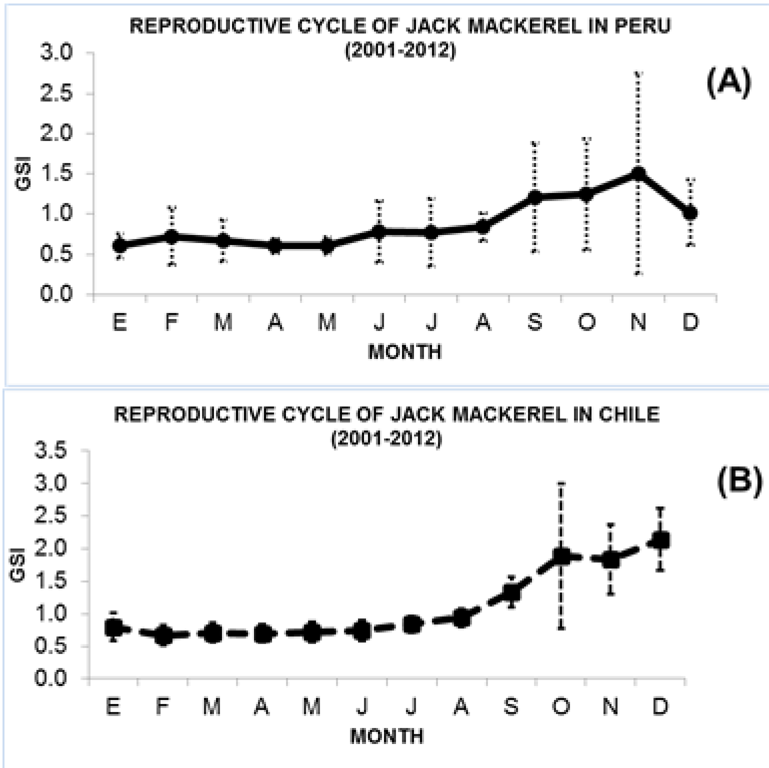

Figure 4: Seasonal change of reproductive activity of jack mackerel in: (A) off Peru, (B) off Chile.

This difference regarding the month where the GSI attains a maximum has also been observed in other pelagic species, such as anchoveta (Chirinos and Alegre, 1969). When comparing maturity data for anchoveta from Peru and Chile they found a mismatch in the month of maximum reproductive activity, being July–February for northern Chile and August–March for northern-central Peru.

The spawning activity is strongly influenced by environmental variability, and the different stocks and species adapt their spawning timing to time windows or time periods with lower environmental uncertainty and higher probability for survival for their spawning products. Therefore, the asynchrony in the maximum period of reproductive activity between the jack mackerel off Peru and that of the jack mackerel off the center-south of Chile might be the result of a different response of these stocks to different environmental regimes.

Spawning time amplitude and variability

There are three interesting differences in the reproductive cycles shown in Fig. 4 that might be indicative of differential long-term adaptations in the reproductive strategy: the period of maximum spawning in central-southern Chile is 3 months whereas in Peru is somewhat wider, up to 4 months; the mean monthly values of GSI of jack mackerel off Peru are lower than those of jack mackerel off Chile; and finally, the standard deviation of GSI at the maximum reproductive activity is higher in Peru than in Chile. The wider amplitude of the spawning period and the higher standard deviation of GSI are clear signals of a differential response to a more uncertain environment off Peru and within this context, the lower values of GSI could be a sign of higher batch fecundity again, in response to different environmental conditions.

3.5 Ecological aspects

3.5.1 Spatial distribution

The spatial distribution of the jack mackerel off Peru is wide and occupies all the Peruvian sea and the adjacent high sea, as can be observed from the Peruvian jack mackerel catches recorded during commercial fishing operations and scientific resource surveys conducted between 1980 and 2012 (Fig. 5), and the fishing activities of the ex-URSS off Peru between 1972 and 1982 (Kuznetzov, 1994)

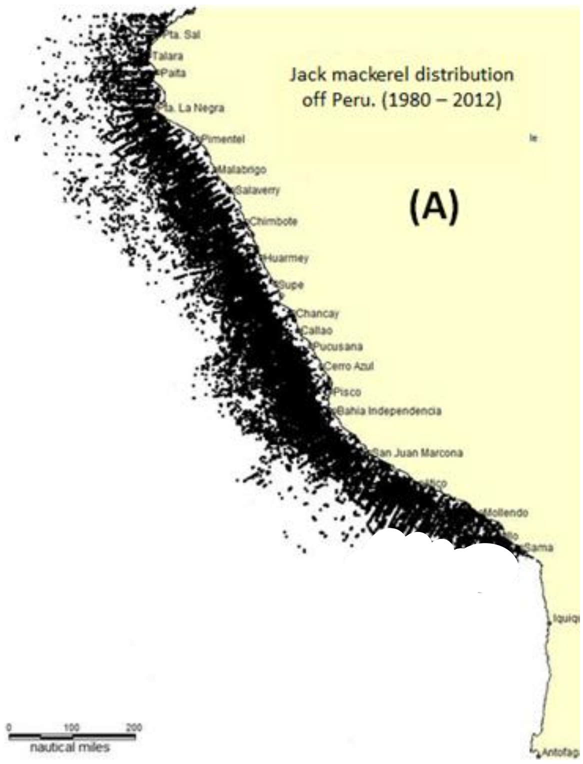

Figure 5. Distribution of jack mackerel off Peru of Peruvian fleet (1980-2012)

The northern part of Peru (north of 06°S) is the southern limit of the biogeographic region called Panamanian province (Balech, 1954) characterized by the high diversity of tropical species. This characteristic have determined that some species of the Peruvian sea, such as, for instance hake have a latitudinal gradient in size structure (Espino et al, 1995; Guevara-Carrasco and Lleonart, 2008), with larger/older individuals in the north and smaller/younger individuals in the south, on what is an evidence of a northward migration along their life cycle. In the north, larger/older individuals have a more diversity of food. This pattern has also been observed in anchoveta and sardine. A similar pattern is observed for jack mackerel off Peru (Fig. 6) (Dioses y Ñiquen, 1988; Dioses, 1995).

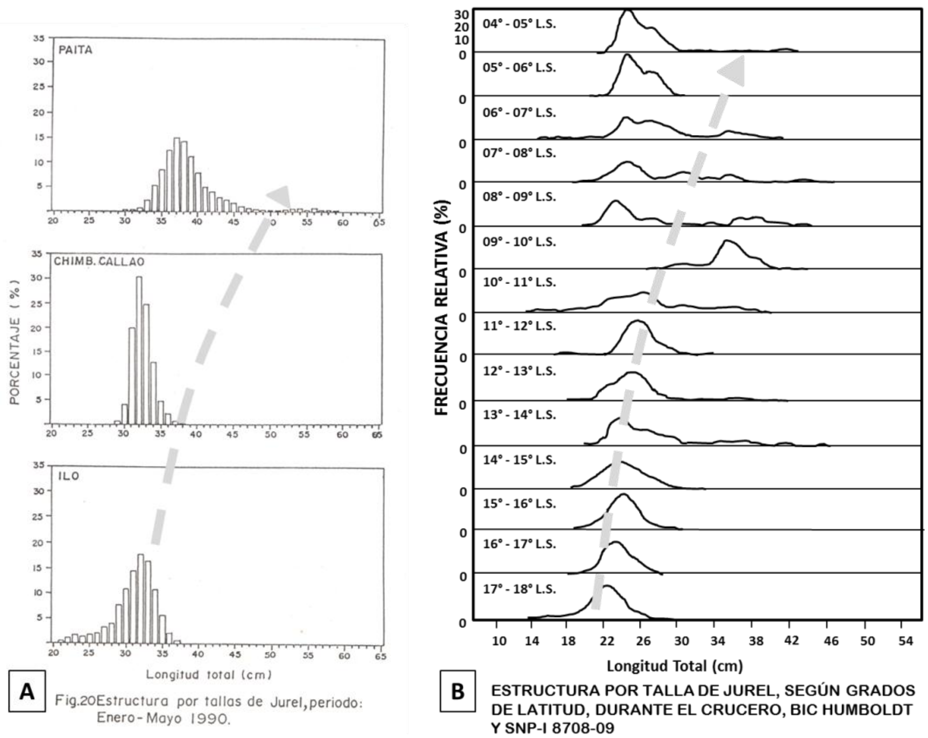

Figure 6. Latitudinal pattern of size structure of jack mackerel (A): in the fishery (January to May 1990) (Dioses, 1995), and (B) during a scientific cruise in winter 1987 (redrawn from Dioses and Ñiquen, 1988).

This migration pattern responds to a south-north axis (eventually south-north-west), and not to a north-south-west as proposed by Elizarov et al (1993). In the Peruvian sea, the argument of lack of food for larger individuals does not result valid to explain the migration of jack mackerel towards south-west, as stated by these authors. The simplest explanation (more parsimonious) is that the migration of jack mackerel off Peru responds to a behavioral pattern that is similar to that of the other species sharing the same areas and more or less the same habitats.

3.5.2 Spawning areas

According to Gulland (1971) a stock should be identified on the basis of the spawning area and the reproduction behavior.

The large database representing 40 years of sampling effort by Peruvian scientists was recently compiled and analyzed, and the results confirms that that jack mackerel has a permanent main center of spawning in the Peruvian sea that extends along the entire coastline (Fig. 7). There are some variations between decades in response to variations of the climatic regime in the Southeastern Pacific area.

These results complement and extend our knowledge on the spawning centers of the jack mackerel in the south Pacific. It also demonstrates that this species not only spawns in the southern region of Peru, as proposed by (Elizarov, et al, 1993), but that that the spawning also extends to the whole coast, proving the point that the Peruvian sea always has been a main spawning center for this stock unit.

These results make particular sense if we consider the high productivity of Peruvian waters, including the existence of 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 catch and transport a variety of marine organisms, such as spawning products (eggs and larvae), and probably reduce the offshore transport increasing larval retention.

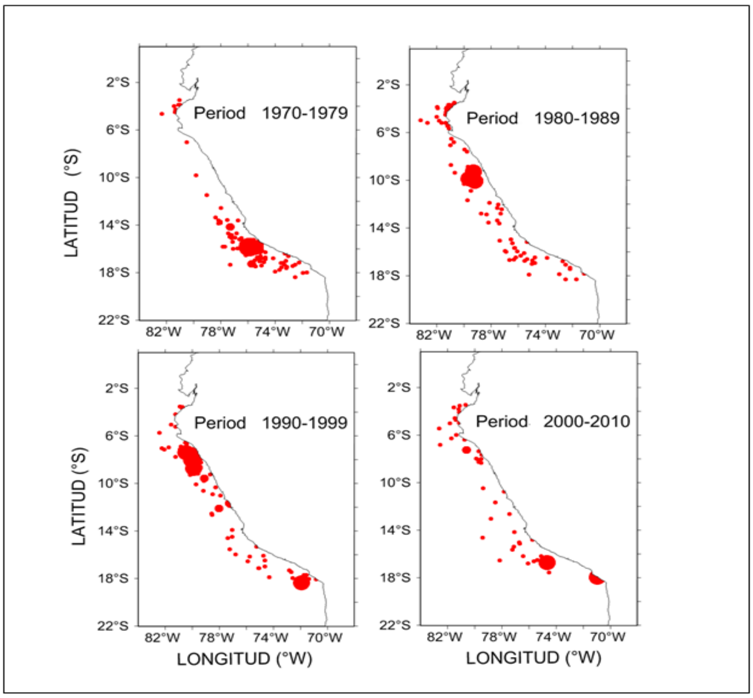

Figure 7. Spawning centers of jack mackerel off Peru (1970 – 2010).

In this respect it is also important to note that the long time series of monthly values of GSI (Fig. 8) supports this observation on the constant presence of reproductive activity of jack mackerel off Peru. This is observed in the permanent seasonal peaks of GSI along the time, with some variability within years but with always permanent reproductive activity even if low in some years, most likely due to the prevailing of not to favorable environmental conditions.

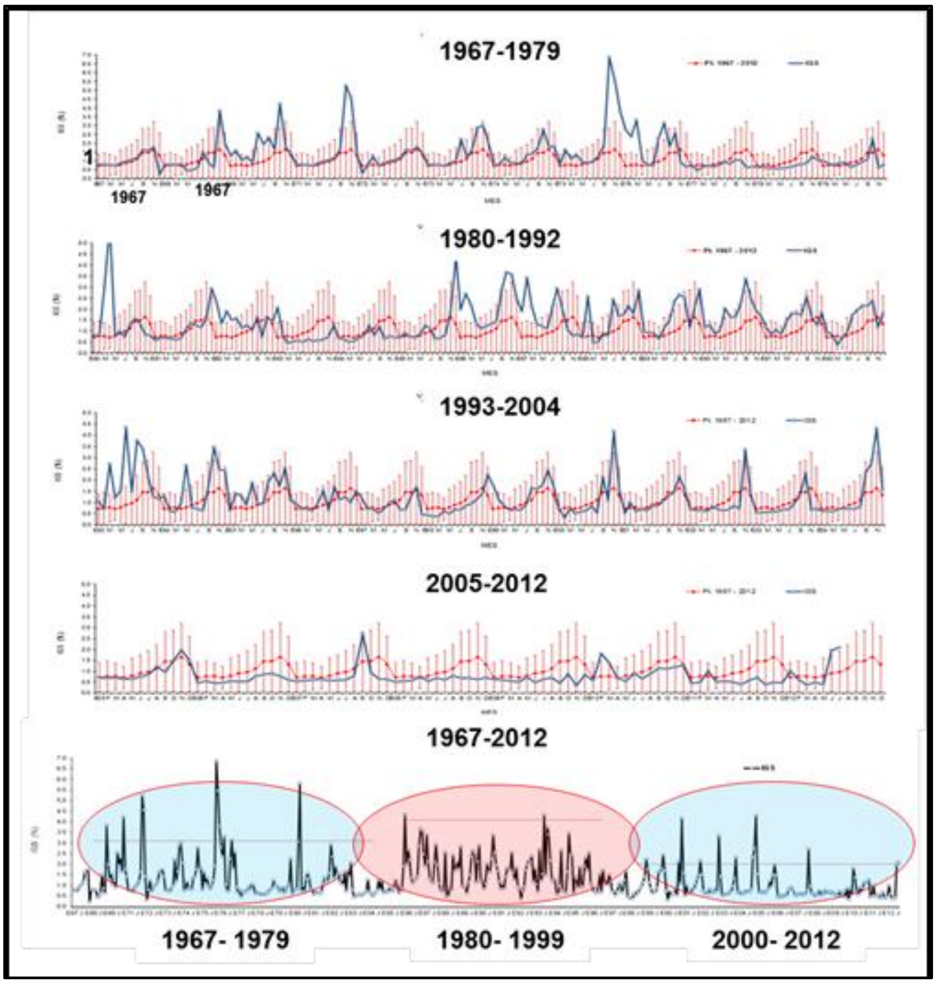

Figura 8. Variation of GSI of jack mackerel in the Peruvian sea, showing seasonal peaks of spawning between 1967 and 2011.

3.5.3 Trophic relationships

The recent analysis of food content of jack mackerel (1977 – 2012) provides a complete spectrum of its diet. Jack mackerel is a species whose diet has a great diversity of preys (Fig. 9), with predominance of euphausids. This group is the most abundant component of the zooplankton community in the Peruvian sea (Ayón, et al., 2011).

Figure 9: Average food spectrum (1977-2011) of jack mackerel in Peru, per range of size (total length). The line indicates the sample size.

The analyses of stomach contents show 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.

Medina and Arancibia (1988, 2002) indicated a higher presence of mesopelagic fish in the diet of jack mackerel off Chile. They also found that euphausids are an important component of the diet but, unfortunately at the writing og this report no further information or data was found to make a more detailed comparison of the diet of jack mackerel in these two areas.

In general, jack mackerel is a 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.

3.5.4 Parasitism.

The use of parasites as biological tags for the identification of stocks is very old (McKenzie, 1987). Unfortunately the studies on parasitism on jack mackerel off Peru are very scanty stock. In a recent study Jara (1998) determined the prevalence of helminthes parasites in 100 specimens, but it only allowed a partial comparison with the Peruvian stock since it mostly focused on jack mackerels caught off Chile. More recently, George-Nascimento (2000) undertook a comparative analysis of parasite communities in jack mackerels from different Chilean localities and concluded that there was evidence in favor of the existence of more than one stock of jack mackerel in the Southeastern Pacific.

4. Conclusions

This report provides some new elements for the discussion and better understanding of the population structure of jack mackerel in the Southeastern Pacific, which strongly supports the hypothesis of the existence of a distinct stock unit of jack mackerel off Peru.

While the area of separation of this stock unit is still a matter worth investigating further, the available scientific information lead us to conclude that, under conditions of certain environmental stability, this area of separation could be represented by the Subtropical Convergence, that is the area of convergence of high salinity Surface Subtropical Water and low salinity Temperate Surface Water (Wyrtki, 1967). Under this hypothesis, the ENSO dynamics introduces an important environmental signal that temporarily breaks the total isolation of the different stock units of jack mackerel and allows at least some recurrent gene flow that keeps the identity of the species without necessarily scrambling the genetic adaptations of the different stocks to the different and varying environmental conditions in the area.

Relatively recent studies on connectivity in marine populations indicate that there is more retention in the spawning zone than what was previously thought, even when there might be a genetic homogeneity at larger spatial scale. In that context, a population managed under the hypothesis of an open population could overestimate the real capacity of population exchange (Cowen, 2000, Cowen et. al, 2007), conducing to undesirable situations.

From the evidence referred to in this report one can conclude that the Peruvian stock of jack mackerel has important characteristics that are sufficiently different from those of other possible stock units in the southeast Pacific. These biological and environmental characteristics could be summarized as follows:

- the habitat, with high productivity related to the high environmental variability,
- a “more r” adaptive response to this habitat (in respect to other stocks of the region),
- faster individual growth,
- a south-north life-history migration pattern with all phases of the life cycle being present off Peru,
- higher plasticity of the reproductive behavior as adaptation to a different and more variable climatic regime,
- comparatively lower size (and age) at first maturity (even under the absence of any significant fishing effects),
- long term stability of size (and age) at first maturity,
- a permanent main spawning center off Peru

While surely more research is needed to define for good the issue of the population structure of jack mackerel in the South Pacific, and the decide of stock units to work with and on where these divisions are for the purposes of the work within the SPRFMO, this report is thought to present enough of the sufficient and necessary elements to consider the Peruvian or northernmost stock of jack mackerel as a separate stock worth being subject to a separate assessments and separated fisheries management.

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