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Evidence of the consistent occurrence of all life-history stages of Jack mackerel
in the northern Humboldt Current System, off Peru and Ecuador

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Evidences of the consistent occurrence of all life-history stages of jack mackerel (*Trachurus murphyi*) in the northern Humboldt Current System, off Peru and Ecuador

by

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SUMMARY

The most distinctive traits of the northern jack mackerel stock that inhabits the northern Humboldt current system off Peru and Ecuador have already been described in earlier contributions and this paper collates the available evidences on the different life-history stages of jack mackerel observed through time off Peru and Ecuador. Which contribute to demonstrate that, in addition to its distinctive traits, the northern jack mackerel stock reproduces and completes its full life-cycle entirely within the northern Humboldt Current System, off Peru and Ecuador. The information analyzed includes larvae distribution and abundance since 1966, length frequency distributions from the commercial fishery since 1972 and from fishery independent research surveys since 1983, and of sexual maturity and spawning since 1967. It is concluded that the information available is solid enough to ratify earlier claims that there is a well-established jack mackerel spawning area off Peru and Ecuador, that there is continuity in the reproductive process within this area, that most if not all the juveniles found off Peru and Ecuador are generated within this area, that juveniles and matured adults of all sizes (and ages) are consistently present in Peruvian waters, and that jack mackerel spawns repeatedly every year off Peru. Thus, providing clear indications that the northern jack mackerel stock reproduces itself and completes its full life-cycle entirely off Peru and Ecuador. Hence supporting the first hypothesis considered by the SPRFMO since 2008, that "*Jack mackerel caught off the coasts of Peru and Chile each constitute separate stocks which straddle the high seas*", with a well-defined self-contained northern stock of jack mackerel off Peru and a separate much larger southern stock off Chile, both straddling albeit not equally, the high seas.

1. INTRODUCTION

During the 11th Meeting of the Science Working Group of the South Pacific Regional Fisheries Organization (SPRFMO) held in Lima, Peru, 15-19 October 2012, the Peruvian delegation presented a paper (IMARPE-PRODUCE, 2012) summarizing the main distinct characteristics of the Peruvian stock (northern stock) of jack mackerel (*Trachurus murphyi*). Further information on the attributes of this jack mackerel stock was provided a year later in the several articles of an IMARPE special publication on the ecology, fisheries and conservation of jack mackerel in Peru (Csirke *et al*, 2013).

In following-up on this important matter, this paper compiles available evidences on the different life-history stages of jack mackerel which have been observed throughout the years off Peru and Ecuador, and which contribute to demonstrate that, in addition to its distinctive traits referred to in IMARPE-PRODUCE (2012), Csirke (2013) and Csirke *et al* (2013), the northern jack mackerel stock reproduces and completes its full life-cycle entirely within the northern Humboldt Current System, off Peru and Ecuador.

The Peruvian Institute of Marine Research (IMARPE) has a long and rich time series of data and observations that go back more than half a century, and are the result of its various research programs that initially were mostly directed to investigate the marine environment and the biology, ecology and population dynamics of the Peruvian anchoveta (*Engraulis ringens*). However, in recent years there have been major efforts to adapt IMARPE's research programs to recover and gather a variety of data and information on other commercially important marine species. Such as jack mackerel, for which there are samples and valuable information of egg and larvae distribution and abundance since 1966, length frequency distributions from the commercial fishery since 1972 and from fishery independent research surveys since 1983, and of sexual maturity and spawning since 1967. All the available data and information on larvae distribution and abundance, length frequency distributions and sexual maturity have been collated and when needed reprocessed and analyzed to produce the various time series presented and discussed below, including some larvae observations from Ecuador.

2. EARLY LIFE-HISTORY STAGES

One of the most important features used to define a fish stock is the continuity of its reproductive process and the relative persistence in the location and spatial distribution of their spawning areas, and where their earlier offspring are found. In the case of the jack mackerel off Peru this have been investigated and documented by Ayon and Correa

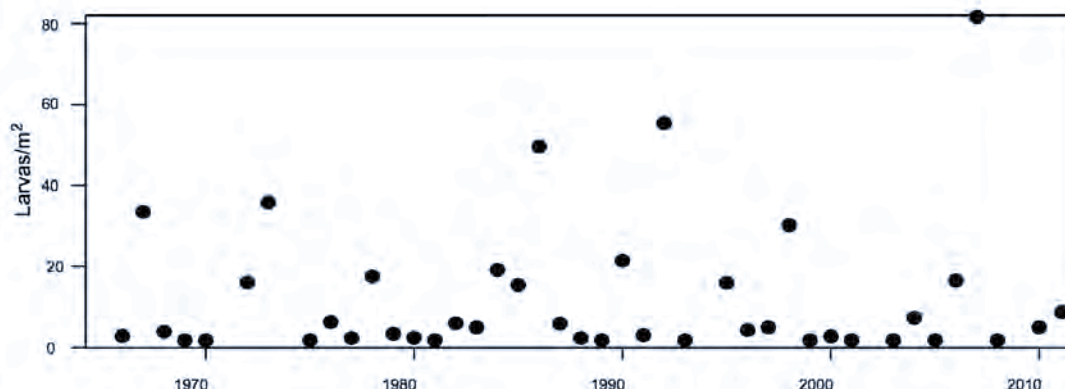


Figure 1.- Annual average abundance of Jack mackerel (*Trachurus murphyi*) larvae off Peru from 1966 to 2012. Updated after Ayon and Correa (2013)

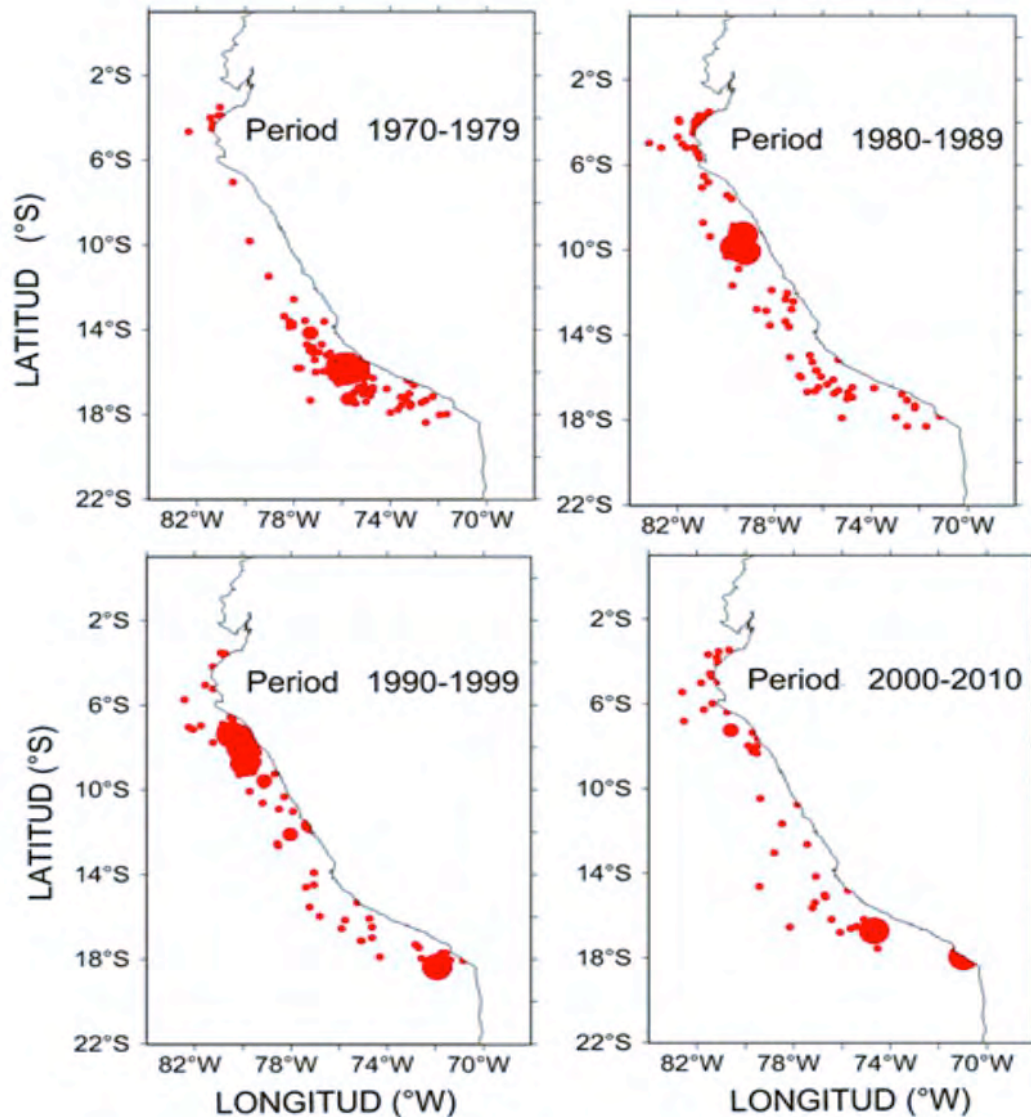


Figure 2.- General distribution pattern of jack mackerel (*Trachurus murphyi*) larvae (in number/m²) off Peru from 1966 to 2016. From IMARPE-PRODUCE (2012)

(2013) through the spatial and temporal analysis of the geographic distribution and abundance of jack mackerel larvae from 1966 to 2010.

As noted in Figure 1, every single year since the first recorded observations in 1966 there have been jack mackerel larvae off Peru, with high variability but with a continued presence from year to year. The annual mean abundance of larvae has fluctuated between a minimum of 3 larvae/m² in the poorest years and a maximum mean of 79 larvae/m² in 2007. This shows that irrespective of the variability, there is a permanent spawning off Peru, which easily translates into a stable presence of a spawning stock.

The spatial distribution of larvae (Figure 2) also shows that the spawning areas and its resultant larvae occur along the whole Peruvian coast, with some long-term decadal latitudinal and longitudinal shifts in the abundance centers of gravity, as already

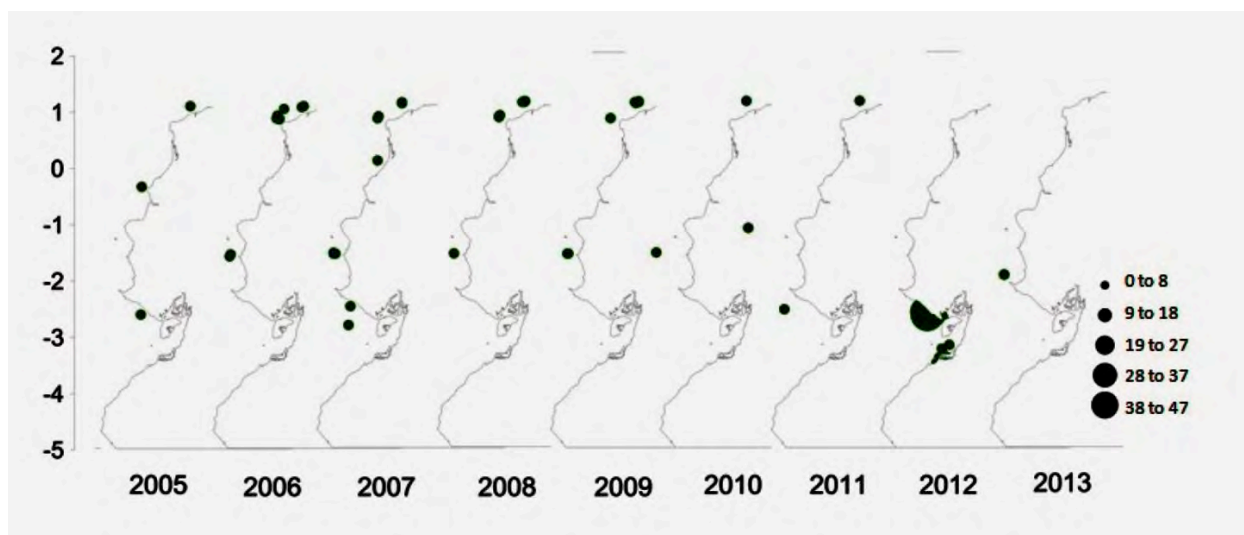


Figure 3.- General distribution of jack mackerel (*Trachurus murphyi*) larvae (in number/10m²) off Ecuador from 2005 to 2013 (from Calderon, 2014)

demonstrated by Ayon and Correa (2013), but with a continued general spread along the whole Peruvian coast, even during periods of lowest abundance.

Similarly, the various research surveys conducted by the National Institute of Fisheries of Ecuador (INP) between 2005 and 2013 (Figure 3) provide a clear evidence of the persistent presence of jack mackerel larvae also off Ecuador, with mean abundances ranging from 2 to 45 larvae/10m² (Calderon, 2014).

Therefore, there should be little doubt that the northern part of the Humboldt Current System, off Peru and Ecuador, is a well-established spawning area for jack mackerel and that there is continuity of the reproductive process, with a continued presence of the earliest life-history stages of jack mackerel. One obvious question would then be, where do these larvae go if they ever make it to the next stage? For this we need to look at the available length frequency records from scientific surveys and commercial catch samplings, to identify the presence of early juveniles.

3. EARLY JUVENILES

Early juveniles of jack mackerel are very difficult to catch with the kind of commercial gears typically used during commercial fishing operations, and even during scientific surveys early juveniles of jack mackerel tend to be poorly represented in the catch samples unless ad-hoc gears are used, which is rarely the case.

Precisely this type of ad-hoc gear, a mid-water Nichimo larvae catcher net specially designed to catch larvae and early juveniles was used during a research survey off Peru organized by IMARPE from 20 November to 19 December 2007 with the Japanese R/V Kaiyo Maru. Although the main purpose of this research survey was to investigate the distribution and abundance of paralarvae of jumbo squid (*Dosidicus gigas*) by towing the Nichimo net in a total of 36 sampling stations along pre-established profiles between latitudes 4°00'S and 16°00'S, early juveniles of jack mackerel were also caught in 18 of

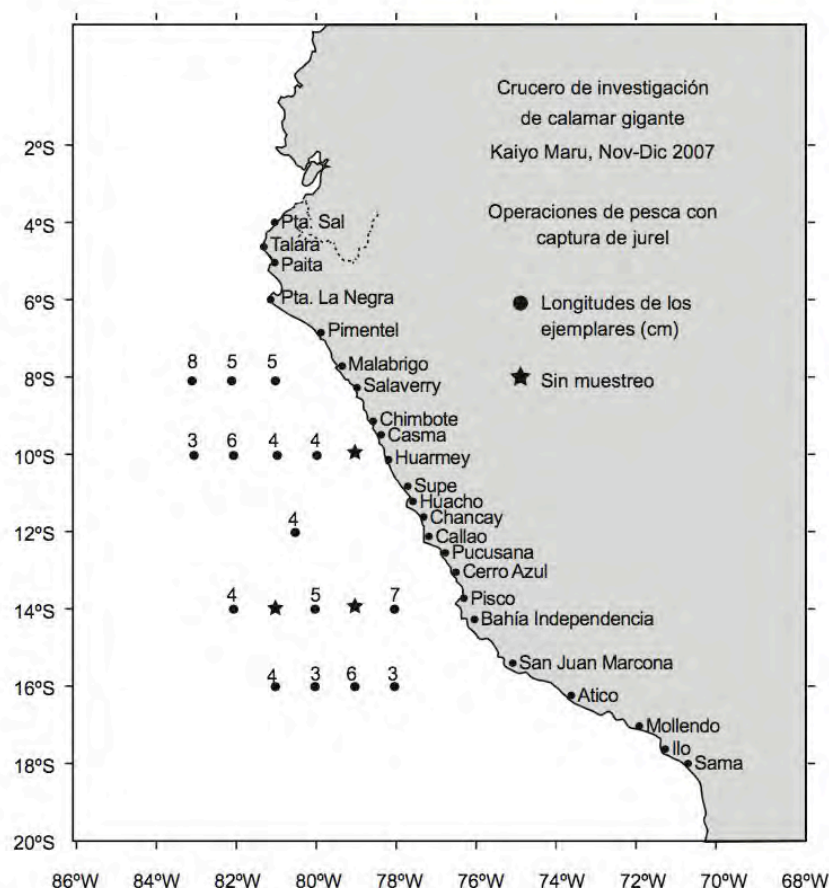


Figure 4.- Geographic distribution and mean total lengths of juvenile jack mackerel (*T. murphyi*) caught in 18 sampling stations using a Nichimo midwater larvae catcher net during a scientific research survey off Peru organized by IMARPE in November-December 2007 with the Japanese R/V Kaiyo Maru (from IMARPE 2008 and Dioses, 2013b)

the 36 trawl samples (Figure 4), at latitudes between Pimentel (6°50'S) and San Juan de Marcona (16°00'S). And, as indicated in this figure, all were small jack mackerels with mean total lengths per station ranging from 3 to 8 cm. Lengths that according to the ageing estimates by Dioses (1995, 2013a) and Goicochea *et al* (2013) would correspond to at most 4-month-old early juveniles.

The presence of early juveniles of 3 to 10 cm in total length, estimated to be 1 to 6 months old, was also reported in samples taken off Peru between July 1977 and July 1979 (Dioses, 2013b), as well as in samples taken during summer 2011 (Goicochea *et al*, 2013).

In addition, the longer time series of annual length frequency distributions from the commercial fishery collected between 1972 and 2017 (Figure 5) also shows the persistent presence of early juveniles, as does in greater detail the monthly length frequencies of jack mackerel caught during IMARPE's scientific research surveys conducted between April 1983 and April 2017 (Figures 6 and 7).

Even if the types of gears used both in the commercial fishery and in the scientific research surveys are poor samplers for small fast-moving juvenile jack mackerels, tending to underrepresent their real abundance in the ocean, their occurrence, even if in low percentages, are a clear and undisputable indication that early juvenile stages of jack mackerel were in fact present when these samples were taken.

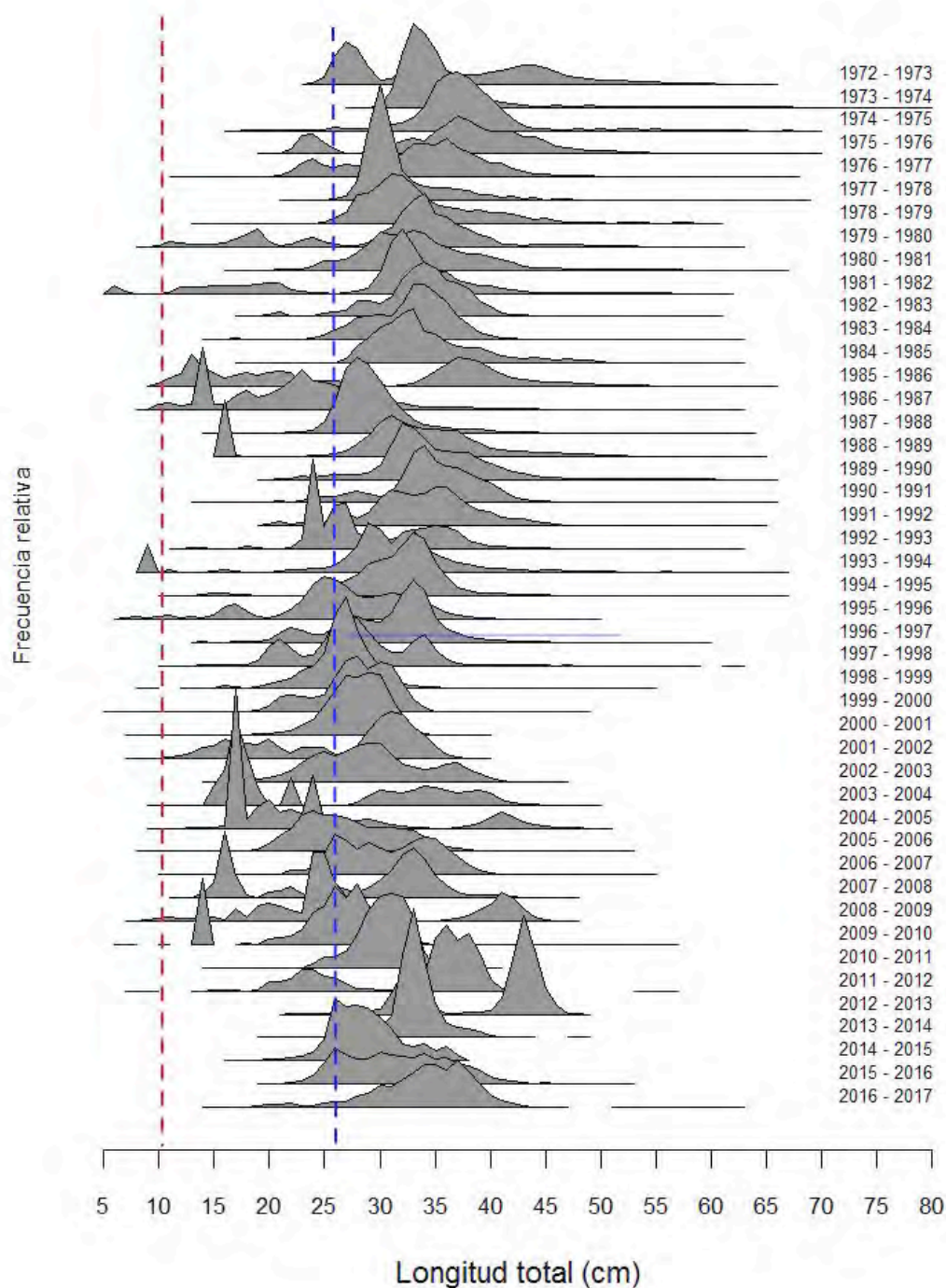


Figure 5.- Annual length frequency distributions (total length in cm) of jack mackerel (*Trachurus murphyi*) caught by the commercial fishery off Peru, by biological year (October to September), from 1972-1973 to 2016-2017. The red vertical broken line crosses at the total length of 10 cm (age \approx 6 months) and the blue vertical line crosses at the total length at first maturity of 26.5 cm (age \approx 2.2 years). Updated after Diaz (2013)

In the case of the annual length frequency distributions of jack mackerel caught by the commercial fishery (Figure 5) it is worth noting that early juveniles of jack mackerel of up to 10 cm total length, estimated to be 6 months old or younger, show up, even if sometimes in very small proportions, in almost half of the biological years sampled

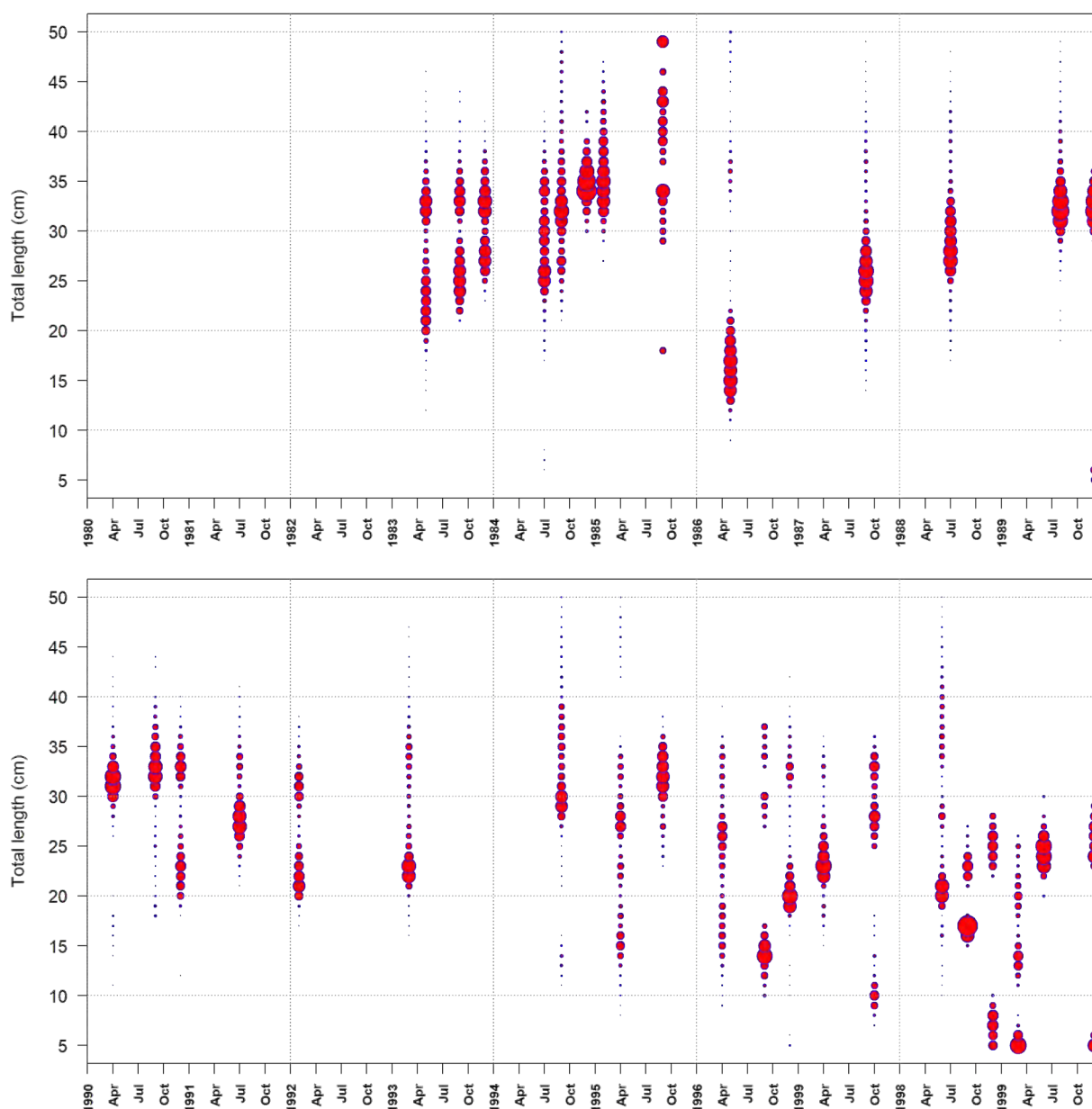


Figure 6.- Monthly length frequency distributions of jack mackerel (*T. murphyi*) caught during scientific research surveys conducted by IMARPE between April 1983 and December 1999

(counted from October to September the following year). In fact, the presence of juvenile jack mackerels of up to 10 cm total length are evident in the length frequency distributions in the biological years of 1976-77, 1979-80, 1981-82, from 1985 to 1987, from 1993 to 1996, from 1997 to 2002, from 2003 to 2007, from 2008 to 2010 and 2011-12.

The more detailed monthly length frequency distributions of jack mackerel caught during 68 scientific research surveys organized by IMARPE between April 1983 and April 2017 (Figures 6 and 7) also confirm the persistent presence of early juveniles, of up to 10 cm total length, estimated to be less than 6 months old. These early juveniles of jack mackerel were also reported in almost half of the 68 scientific surveys, in: July 1984; May 1986;

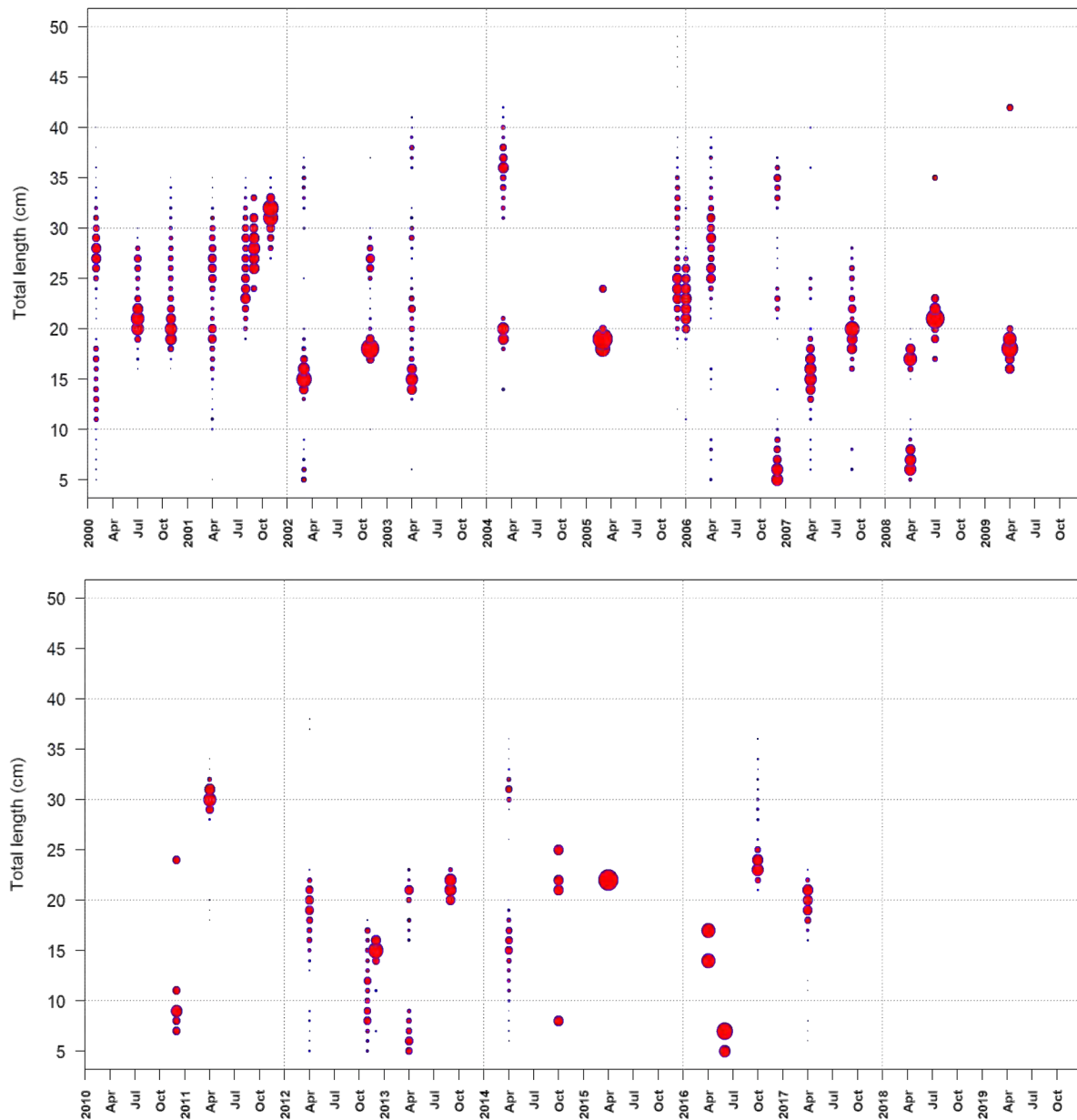


Figure 7.- Monthly length frequency distributions of jack mackerel (*T. murphyi*) caught during scientific research surveys conducted by IMARPE between January 2000 and April 2017

December 1989; April 1995; April, September and December 1996; October 1997; June and December 1998; March and December 1999; February 2000; April 2001; March 2002; April 2003; April and December 2006; April and September 2007; April 2008; December 2010; April, November and December 2012; April 2013; April and October 2014; June 2016; and April 2017.

While the continued presence of larvae clearly indicates continuity in the reproductive process and the existence of a well-established spawning area for jack mackerel off Peru and Ecuador. The concurrent presence of larvae and early juveniles that are only days to a few months older also indicates that at least a fraction of the larvae survive and make it to the next life-history stage within Peruvian (and Ecuadorian) waters; and that most if

not all the juveniles found there are generated within the area. Therefore, weakening any possible support to the hypotheses that these early life-history stages or early recruits may more or less regularly come from somewhere else, either through active migration or by being transported or drifted as suggested by, for instance Corten (2014) and Vazquez *et al* (2015, 2016). In fact, the small sizes and the shortness of time involved in the passage from larvae to early juveniles doesn't leave much space or time to support massive distant migrations or transport of these early life-history stages. And, as noted below, there are also evidences of a continued presence of recruiting juveniles and adults in the same area, off Peru and Ecuador.

4. JUVENILES AND ADULTS

The passage from recruiting juveniles to the adult stage is determined by the size or age at first maturity, and in the case of jack mackerel off Peru the size at first (50%) maturity has been estimated to be 26.5 cm total length (Perea *et al.*, 2013). Which, according to Dioses (1995, 2013a) and Goicochea *et al* (2013), would correspond to an age of about 2.2 years.

Length frequency distributions from the commercial fishery off Peru show that except for the biological year 1973-1974, juvenile jack mackerels (<26.5 cm total length) were present in the commercial catches every single biological year between 1972-1973 and 2016-2017 (Figure 5). Monthly plots of the length frequency distributions from the commercial fishery from 2012 to May 2017 can be found in the Peruvian national reports presented at this and earlier Scientific Committee meetings (IMARPE-PRODUCE 2012, 2013, 2014, 2015, 2016, 2017).

The continued presence of juveniles (<26.5 cm total length) is also evident in the more detailed monthly records of length frequency distributions of jack mackerel observed during scientific research surveys organized by IMARPE since April 1983 (Figures 6 and 7) where, except for 3 surveys in December 1984, January 1985 and November 2001, juveniles of jack mackerel show-up in every other survey between 1983 and 2017. Proving once more that, although with high yearly variability, there is a continued presence of recruiting juveniles of jack mackerel off Peru.

There are also sporadic reports of the occurrence of juvenile and adult jack mackerels off Ecuador in 1983, 1984 and 1991 (Aguilar, 1993). And there are reports of continued although highly variable catches of jack mackerel off Ecuador from 1987 to 2012, with sizes ranging from 19 to 66 cm total length between 1987 and 2001, from 25 to 32 cm in 2011, and from 32 to 46 cm in 2013 (INP, 2013).

Matured adult jack mackerels of all sizes (and ages) are also consistently present in Peruvian waters, as shown in Figures 5, 6 and 7, even if there seems to be a diminished occurrence of adult jack mackerels in the length frequency samples taken during surveys since 2012. However, length frequency samples from the commercial fisheries continue to show the continued presence of all size groups, including adults, as shown in Figure 5 and reported in more detail by IMARPE-PRODUCE (2012, 2013, 2014, 2015, 2016, 2017). In addition, this uninterrupted presence of all size groups (or size/age life-history stages) was further confirmed by Diaz (2013) when he was able to follow, and fit a growth curve to, the length modal progression of a single strong year class of jack mackerel from January 2002, when it had a modal size in 12 cm, to march 2005 when it reached a modal size of 40 cm.

If there is a continued presence of matured adults there should also be a continued presence of spawners, a much-needed life-history stage for jack mackerels in the northern stock to sustain itself and successfully complete their life cycle year after year.

5. SPAWNERS

In fact, as already noted by IMARPE-PRODUCE (2012) and Perea *et al* (2013), the analyses of the monthly fluctuation of the gonadosomatic index (GSI) and the reproduction activity of jack mackerel off Peru since 1967 shows that for the last five decades jack mackerel has spawned regularly every year off Peru, with a single extended spawning period that usually last from August to December and peaks in November (Figure 8). This, added to

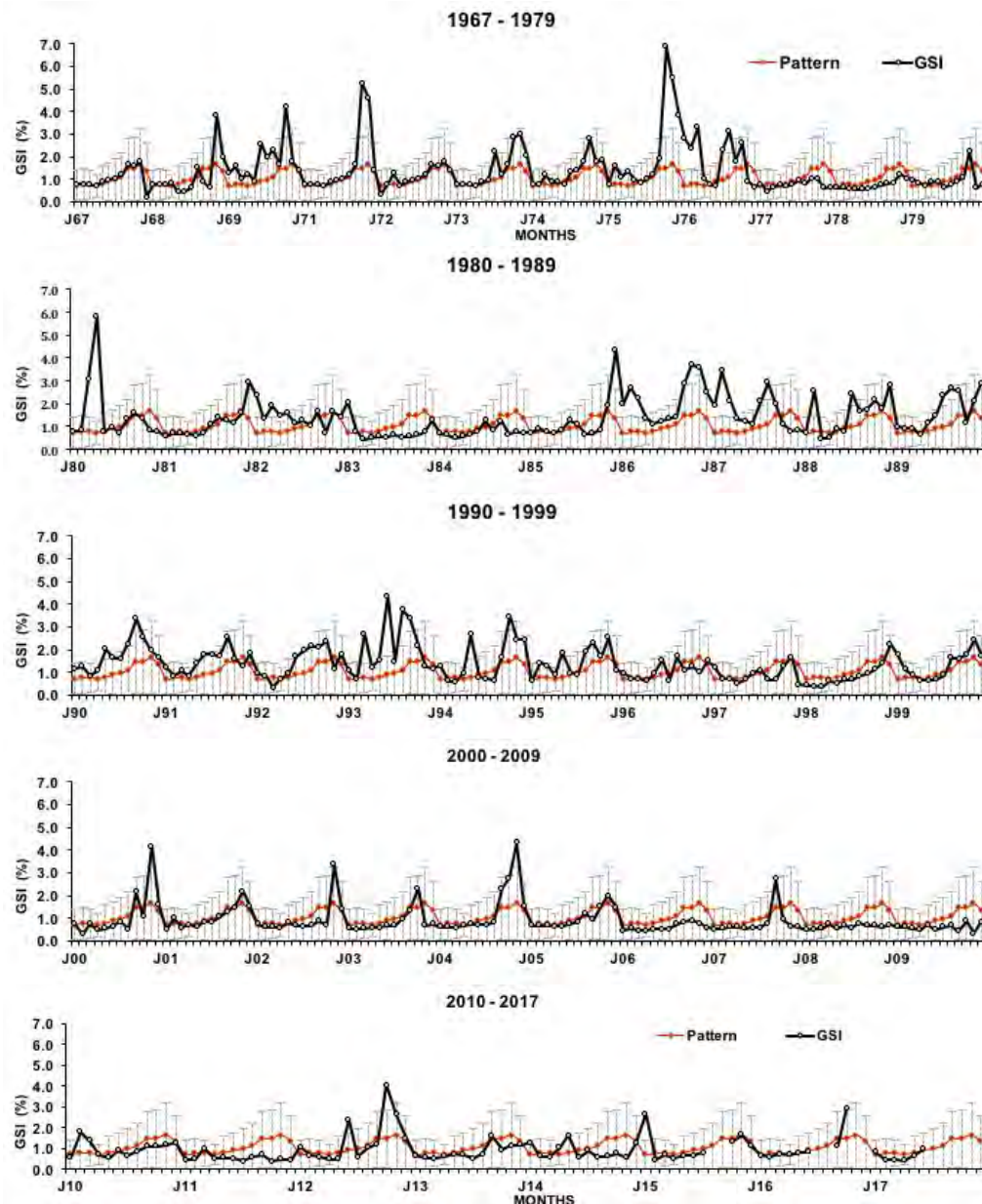


Figure 8.- Monthly gonadosomatic index (GSI) of jack mackerel (*T. murphyi*) captured off Peru between January 1967 and June 2017 (black lines and open round markers). The red lines and dots represent the mean monthly GSI pattern and the vertical grey broken lines represent the variance around the monthly mean GSI. Updated after IMARPE-PRODUCE (2012) and Perea *et al* (2013)

the continued presence of an adult population, that spawns, and the continued presence of their offspring reaffirms the completeness of the life-cycle of the jack mackerel stock off Peru.

6. DISCUSSION AND CONCLUSIONS

IMARPE-PRODCE (2012), Csirke (2013), Csirke *et al* (2013) and also Gerlotto *et al* (2016) provide an ample account of the most distinctive traits of the northern stock of jack mackerel that inhabits the northern Humboldt current system off Peru and Ecuador, also known as the Peruvian jack mackerel stock or, more simply, the northern stock.

This account of distinctive traits is expanded and complemented here with a review of the different life-history stages of jack mackerel occurring off Peru and Ecuador and, as a result, it is concluded that the available evidences of both, the distinctive traits and the consistent occurrence of all life-history stages of jack mackerel (*Trachurus murphyi*) off Peru and Ecuador are sufficiently solid to ratify earlier claims that:

- the area of the northern Humboldt Current System off Peru and Ecuador is a well-established spawning area for jack mackerel;
- there is continuity in the reproductive process of jack mackerel within this area;
- most if not all the juveniles found off Peru and Ecuador are or appear to be generated within this area;
- juveniles and matured adults of all sizes (and ages) are consistently present in Peruvian waters; and,
- for the last five decades jack mackerel has spawned repeatedly, every year, off Peru.

Therefore, there seems to be no good reason to doubt that the jack mackerel stock off Peru and Ecuador reproduces itself and completes its full life-cycle entirely within the northern Humboldt Current System, off Peru and Ecuador. Hence undeniably supporting the first hypothesis considered in SPRFMO (2008). That is, that *“Jack mackerel caught off the coasts of Peru and Chile each constitute separate stocks which straddle the high seas”*. We can conclude then, that there is a well-defined self-contained northern stock of jack mackerel off Peru and that there is a separate much larger southern stock off Chile, both straddling albeit not equally, the high seas.

The above observations don't totally exclude the possibility of some level of overlap, sporadic latitudinal shifts and possible mixing between jack mackerel in southern Peru and northern and even central-southern Chile, related to environmental factors and oceanographic changes such as, for instance, those associated with strong El Niño or La Niña. Including those that may be caused by retention, dispersion and transport mechanisms as suggested by Vásquez *et al* (2016), or by expansions and contractions of 'environment-bounded habitat metapopulations', as suggested by Gerlotto *et al* (2016).

These, however, are bound to be sporadic and short-lived events that, other than stirring and enriching their genetic pool, don't seem to have other noticeable long-lasting impacts on the northern jack mackerel stock. Since, for instance, there's evidence that off Peru jack mackerel has spawned repeatedly every year during the last 50 years, as shown by the work with matured and spawning stages by Perea *et al* (2013) and with larval stages by Ayon and Correa (2013). Also, the spawning areas as described by the overall distribution and centers of gravity of jack mackerel larvae have always remained within the northern Humboldt Current System area, off Peru, as shown by Ayón and Correa (2013). And, in addition to larvae, the whole range of sizes (and ages) of juvenile and adult

jack mackerels have consistently been present off Peru, as shown by the length frequency distributions referred to earlier in this paper.

All this wealth of data and information, we believe, shall fully satisfy the requirement that for fisheries management to be successful, the stock to be assessed and managed needs to be properly identified on the basis of its spawning area and its reproduction behavior (Gulland, 1971); and that a stock or group of fish subject to a fishery and to a common management regime needs to have at least two main attributes: their individuals must be able to reproduce amongst themselves, and must have similar life-history characteristics (Hilborn and Walters, 1992).

In concluding, it is worth stressing that jack mackerel off Peru (and Ecuador) have a well identified spawning area, have a well-defined reproduction pattern, are able to reproduce amongst themselves, and share similar life-history characteristics that, as noted by IMARPE-PRODCE (2012), Csirke *et al* (2013) and Gerlotto *et al* (2016), are in some aspects different from those of jack mackerel in the much larger southern stock, that is distributed and exploited off central-southern Chile.

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