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**10TH SCIENTIFIC WORKING GROUP MEETING**
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# Report of 2011 SNP Workshops on Acoustic and Geoestatistical Assessment of abundance, distribution changes and size structure of Jack Mackerel (*Trachurus murphyi*) during first half of 2011 within the Peruvian EEZ

**SOCIEDAD NACIONAL DE PESQUERÍA - SNP**
**National Fisheries Society – SNP**
**Lima, Perú, September 2011**

## 1. ABSTRACT

During the First International Workshop on Chilean Jack Mackerel (Santiago, June 2008) a proposal was made by the Peruvian Delegation for using explicit spatial data[1]: *"Fisheries management might consider an approach in which the habitat range for every target species is known, not only its biomass or the population structure. This requires a frequent monitoring and data collection effort, and the possibility of using fishing vessels as continuous samplers (e.g. using acoustics) opens a good opportunity to obtain information on habitat characteristics"*. Therefore it was later submitted to SPRFMO a new document (2009) regarding the protocols required for implementing the use of fishing vessels data to support fishery management[2]. Also during the Second International Workshop on Chilean Jack Mackerel (Lima, May 2009, 7th SWG meeting) a new contribution regarding the need of loading explicit spatial data into the study of the ecosystem[3] was submitted.

The Sociedad Nacional de Pesquería (SNP) conducted a preparatory meeting during December 2010 in order to plan a series of workshops to be executed during 2011 in order to take advantage of the experience of Peruvian fishing industries regarding acoustic surveying based on data collection aboard fishing vessels. The data included digital echograms, VMS, purse seine catch data, fish length sampling and satellite oceanographic information. Analysis included acoustic and geostatistical assessment of fish abundance on geographical changes in distribution, fish length time series and a description of local abundance in relation to oceanic conditions. A calculation was also included for by catch on high seas species whose exploitation still is not regulated by SPRFMO. This document summarizes the main analysis made on the data collected during the first half of 2011.

Differently to what was observed between 2008 and 2010, during summer 2011 it has been produced along Peruvian coast a confluence of water masses with negative thermal anomalies from the north, and

[1] Gutierrez M., A. Bertrand, M. Ballon, P. Espinoza, A. Alegre, F. Gerlotto. 2008. Distribution changes and interactions of Jack Mackerel off Peru as observed using acoustics (1983-2008). SPRFMO International Workshop on Chilean Jack Mackerel. Santiago, Chile, June 30 – July 4, 2008. (SP-07-JM-SA-08).
[2] Karp W., R. Kloser, F. Gerlotto, H. Peña, M. Gutiérrez. 2009. Guidelines for Acoustic Data Collection aboard Fishing Vessels operating in the SPRFMO area. Technical document submitted to SPRFMO by the Peruvian Delegation.
[3] SNP. 2009. Ecosystem indexes obtained from fishing monitoring, a methodological proposal on direct stock assessment for marine resources of the SPRFMO area (SP-07-JM-SA-08).

positives from the south along the Peruvian coast. At the same time a sustained upwelling was observed which implied the formation of high concentration zones for zooplankton, facilitating the aggregation of clusters of Jack Mackerel (JM). JM was observed at very low densities and small sizes during the past years: this fact allowed better perspectives for the fishery for the current year. Therefore it was decided to perform a diagnostic based upon information collected by the fleet.

The analysis of the environmental conditions showed that particular characteristics of the ongoing confluence between ACF[4] and ASS[5] produced a narrow mixed zone along the coast since early 2011 then stretching the JM habitat and allowing a sustained fishing season after 5 years of almost no catch. The modal progression of the main observed cohort of Age-3 is consistent with IMARPE's monitoring made by late 2007 regarding a significant spawning and later detection of JM juveniles along a wide oceanic zone far from coast.

Taking advantage of the availability of digital echosounders aboard the fishing vessels and fishing sets made during the current JM fishing season (January 16 to May 20), the JM abundance of Peruvian stock was calculated using geostatistics and acoustic methods as well as an analysis of the changes in distribution according to the environmental conditions and the population structure. The analysis permitted to conclude that a significant recruitment occurred that provides good perspectives to JM for displaying relatively high densities as long as the environment remains stable during this year, without taking into account possible new recruitments and the arrival of other bigger sized cohorts from the South Pacific.

The biological sampling showed a modal progression of a JM cohort from 29 to 32 cm in five months (January-May) though the existence of a second modal group averaging 27 cm was possible. The JM catches and the ones for Mackerel (*Scomber japonicus*) during 2011 (up to May 20) represented 95,129 t (92.89%), and 7,286 t (7.11%) respectively (non official values). The averaged weekly abundance measured using geostatistics indicated 168 kT (thousands of tons) with peaks in 639, 497 and 488 kT. The acoustic calculation reached up a fortnight average of 300 kT, with peaks in 481, 460 and 435 kT. Nevertheless it must be taken into account that assessments described are only representative of the areas were the fleet operated.

## 2. INTRODUCTION

### 2.1. On the use of acoustic data collected aboard fishing vessels.

Digital echosounders are progressively deployed as standard equipment aboard fishing vessels. They give an opportunity to collect data for qualitative and quantitative purposes regarding ecosystem functioning. This relatively new technological generation of sounders includes hard disks for data file storage and/or Lan ports for external data archiving.

Some acoustic indicators of ecosystem functioning can be extracted from digital echograms (data files) using analysis software:

[4] ACF: Coastal Cold Water : Aguas Costeras Frías: relatively low temperatures, salinity from 34.8 to 35.0 ups
[5] ASS : Subtropical Surface Waters: Aguas Subtropicales Superficiales: relatively high temperatures, salinity higher than 35.1 ups

- Precise location (date, time, lat./lon., depth) of each and every detected fish schools, zooplankton and midtrophic micronecton aggregations.
- Backscattering strength for every target, which is a proxy of weight/abundance, and statistical indexes of internal structure such as skewness, kurtosis, fractal dimension etc.
- Depth of thermocline.
- Depth of oxycline.
- Internal wave dimensions.

These sources of information can be used for:

- Fish and school behavior studies.
- Inter species interactions analysis.
- Index of habitat range suitability for groups of species.
- Target Strength measurements.
- Prey-predator relationships observations.
- Ocean dynamics when data is related to satellite information (e.g. altimetry).
- Availability/catchability indexes.
- Dyel dynamics of species.

The possibility of using industry vessels for building up time series on indicators is not intended to replace scientific surveys and ecological modeling but is considered as a complementary source of information since fishing vessels operate over longer time and range scales compared to research vessels. Therefore there is a need to achieve two basic conditions regarding the use of fishing vessels as platform of opportunity:

- (1) The availability of technical protocols to ensure minimum conditions aboard to gather quality data under certain standards (calibration, noise measurement, biological sampling etc).
- (2) The availability of protocols and formats for logistics of data management and exchange.

### 2.2. About the use of data collected by fishing vessels in Peru

During the Chilean Jack Mackerel Workshop (Santiago, June 2008) a proposal was made by the Peruvian Delegation for using explicit spatial data[6]: *"Fisheries management might consider an approach in which the habitat range for every target species is known, not only its biomass or the population structure. This requires a frequent monitoring and data collection effort, and the possibility of using fishing vessels as continuous samplers (e.g. using acoustics) opens a good opportunity to obtain information on habitat characteristics"*.

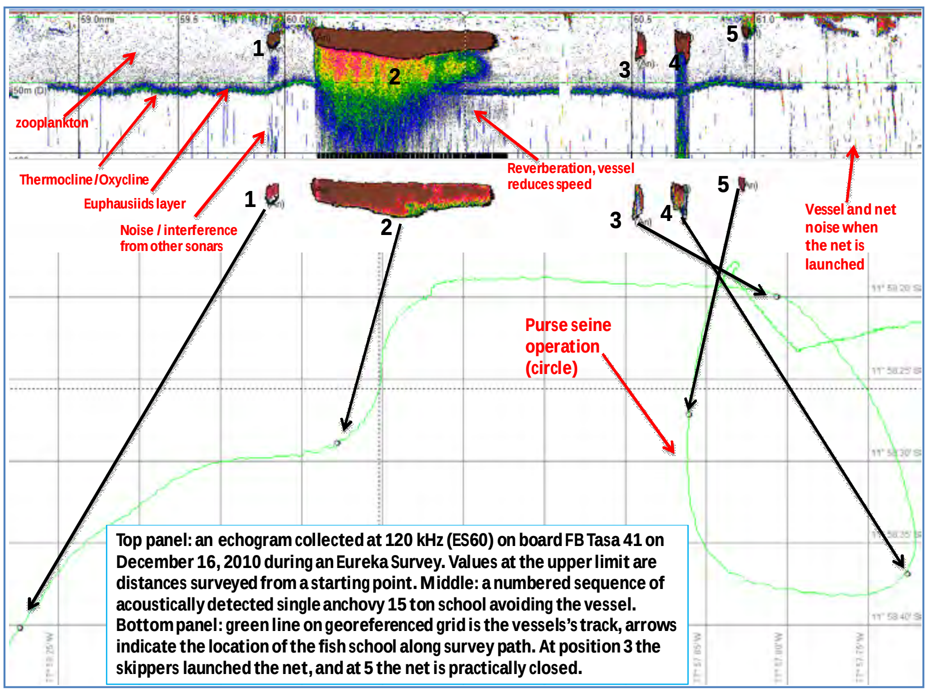
Based on the ICES Cooperative Research Report 287[7] a voluntary task group of the Fisheries Acoustics Science and Technology Working Group (FAST-WG) of the International Council for the Exploration of the Sea (ICES) drafted and submitted to SPRFMO a new document regarding the specific protocols

[6] Gutierrez M., A. Bertrand, M. Ballon, P. Espinoza, A. Alegre, F. Gerlotto. 2008. Distribution changes and interactions of Jack Mackerel off Peru as observed using acoustics (1983-2008). SPRFMO International Workshop on Chilean Jack Mackerel. Sanatiago, Chile, June 30 – July 4, 2008. (SP-07-JM-SA-08).

[7] ICES. 2007. Collection of Acoustic Data from Fishing Vessels. Karp W., J. Dalen, R. Kloser, G. Macaulay, G. Melvin, R. Mitson, R. O'Driscoll, H. Peña, T. Ryan. 2007. ICES Cooperative Research Report n° 287.

needed for implementing the use of fishing vessels data to support fishery management of Jack Mackerel (*Trachurus murphyi*; JM)[8]. Also during the Second International Workshop on Jack Mackerel (Lima, May 2009, 7th SWG meeting) a new contribution was submitted regarding the need for loading explicit spatial data into the study of the ecosystem[9]. During their annual meetings in 2010 and 2011 The FAST-WG conducted special sessions devoted to organize a support to SPRFMO regarding the topics listed in the 2.1. section of this report, and specific contributions were discussed[10,11,12] (cf. report R. Kloser, this meeting).

Based on those contributions SNP with IMARPE and IRD conducted a preparatory meeting during December 2010 in order to plan a series of workshops to be executed during 2011 in order to take advantage of: (1) the experience of Peruvian fishing industries regarding acoustic surveying on Jack Mackerel and (2) data collection aboard fishing vessels. The data included digital echograms, VMS, purse seine catch data, fish length sampling and satellite oceanographic information. Analysis included acoustic and geoestatistical assessment of fish abundance and geographical changes in distribution, fish length time series and a description of local abundance in relation to oceanic conditions. A calculation of by catch on high seas species whose exploitation still is not regulated was also included.




**Top panel: an echogram collected at 120 kHz (ES60) on board FB Tasa 41 on December 16, 2010 during an Eureka Survey. Values at the upper limit are distances surveyed from a starting point. Middle: a numbered sequence of acoustically detected single anchovy 15 ton school avoiding the vessel. Bottom panel: green line on georeferenced grid is the vessels's track, arrows indicate the location of the fish school along survey path. At position 3 the skippers launched the net, and at 5 the net is practically closed.**

Fig.1. A sample of virtual analysis during the SNP preparatory meeting (December 2010): high resolution echogram and available elements to measure the behavior of fish and fisher after, during and before a fishing set besides the vertical habitat range and availability of preys.

This document provides a summary of two workshops carried out by The Sociedad Nacional de Pesquería (SNP) with support and participation of the Universidad Nacional Federico Villarreal (UNFV),

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[8] Karp W., R. Kloser, F. Gerlotto, H. Peña, M. Gutiérrez. 2009. Guidelines for Acoustic Data Collection aboard Fishing Vessels operating in the SPRFMO area. Technical document submitted to SPRFMO by the Peruvian Delegation.

[9] SNP. 2009. Ecosystem indexes obtained from fishing monitoring, a methodological proposal on direct stock assessment for marine resources of the SPRFMO area (SP-07-JM-SA-08).

[10] Gutiérrez M., E. Mendez. 2010. Acoustic monitoring of ecosystem functioning off Peru based on industry vessels data. FAST-ICES-WG annual meeting. SWNFS, NOAA, San Diego, April 2010.

[11] Gerlotto F., M. Gutierrez, A. Bertrand. 2010. The distribution of jack mackerel Trachurus murphyi in the South Pacific Ocean: a metapopulation hypothesis. FAST-ICES-WG annual meeting. SWNFS, NOAA, San Diego, April 2010.

[12] Gerlotto F., M. Gutierrez, E. Josse, A. Aliaga. 2011. Acoustic data from fishing vessels: what scientific information can be obtained from the Peruvian jack mackerel fishery ? FAST-ICES-WG annual meeting. SWNFS, NOAA, Reyjavik, May 2011.

the French Institute of Research for Development (IRD) and The Instituto del Mar del Perú (IMARPE). A previous preparatory workshop was carried out on the base of the recommendation listed during the preparatory meeting in December 2010. The first workshop on assessment of Jack Mackerel was carried out at UNFV during 21-15 March, and the second at SNP during 25-27 May.

**2.1 Status of the Peruvian Jack Mackerel population during first half of 2011**

After 5 years of absence a significant abundance level of JM was detected, and after 3 years of no catch it became possible to keep a fishing effort to continuously supply the direct human consumption industry in Peru. During the 2 past years the presence of juveniles with growing size in the catches of anchovy fleet has been observed continuously, and also in the catches of the artisan fleet operating along the Peruvian south coast, which was an indication of a possible recovery of the Peruvian stock (or metapopulation).

Fig.2. juvenile jack mackerel individuals below 22 cm length caught at Atico (16°15'S) during October 2009. Industrial fleet cannot operate inside the first 10 nm, that area being reserved for the artisanal fleet operating to supply fish for local markets. Under certain condition the government can close fishing grounds even for the artisan fleets.

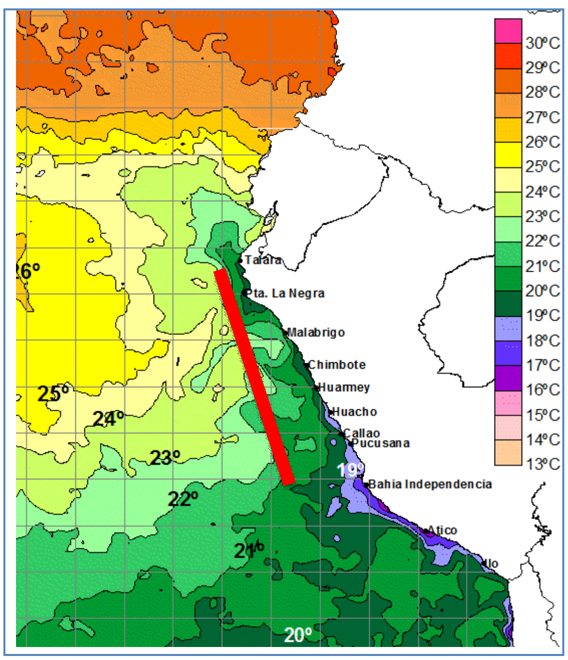


Fig. 3. Sea Surface Temperature as observed on May 24, 2011. The red line indicates the approximate location of the front between oceanic and coastal waters. The particular conditions observed in Peru after 10 years produced a narrow band of mixed waters in which jack mackerel aggregated during the first half of 2011.

La Niña conditions observed since June 2010, which lasted until February 2011, conduced to neutral conditions until April, then again prevailed warmer anomalies until August. Nevertheless the mixed zone between coastal (ACF) and oceanic waters (ASS) has had a relatively reduced area, then contributing to concentrate JM relatively close to the coast. The thermocline appeared deeper than during past years (70 m depth).

The information continuously collected by the SNP companies regarding fishing sets since January showed the JM preference to distribute along the oceanic front between ACF and ASS in all places where it was caught. Nevertheless there was a change in the distribution of fishing grounds from north to south following the influx of AES when a Kelvin Wave advected oceanic water masses from the northwest. This intrusion was followed up throughout the daily progression of thermal anomalies (ATSM[13]).

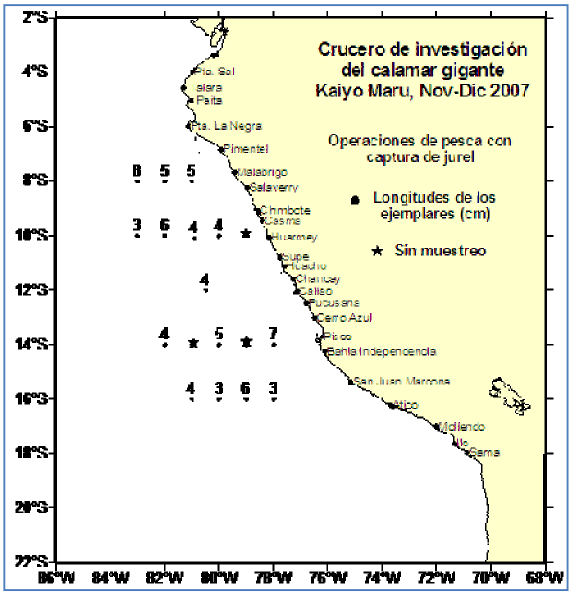


Fig. 4. Distribution chart of 18 sampling points performed by RV Kaijo Maru between November and December 2007. A Nichimo net was used to catch Jack Mackerel individuals of 0 age dispersed 15 times. The wide area of distribution is no detectable with conventional surveys.

Since January JM size increased from 26 to 37 cm (total length). During the first weeks of the fishing season individuals were caught with a mode of 28 cm that progressed up to 32 cm in May (week 20). This cohort corresponds to JM of age 3 and possibly born during the 2007 spawning season according to the time series of IGS[14].

To support this hypothesis it has been possible to access new information about the presence of young individuals (3-8 cm) caught during biological sampling made by the RV Kaiyo Maru between November and December 2007 (Fig.4), which indicated a unsuspected and widely distributed spawning toward the north and west of the usual distribution area of JM.

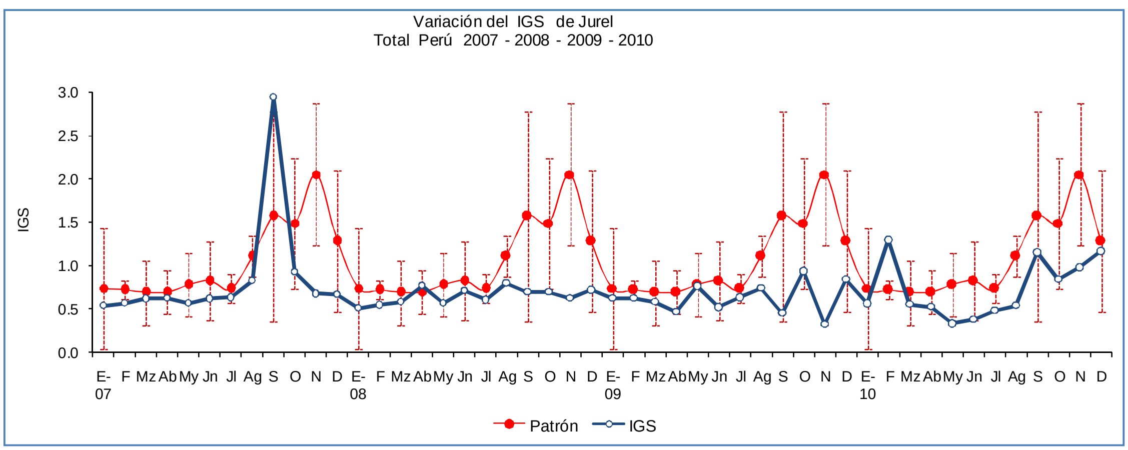


Fig.5. Time series of monthly IGS between January 2007 and December 2010. The observed value during August and September 2007 is over the average pattern (1997-2010) which is an indication of an important spawning and consistent with the recruitment observed since early this year.

This new evidence matches with it what was detected previously by IMARPE. According to its IGS time series an important spawning was produced between August and September of 2007. Then a La Niña event developed from 2007 to 2008, and strong upwelling might have pusehd away the JM distribution. This circumstance deserves an enhanced monitoring and biological sampling with support of SNP.

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[13] Thermal Anomaly of the Sea Surface: difference between the termal pattern and measured value, in Celsius degrees.
[14] IGS: spawning index (Indice Gonadosomático)

## 3. OBJECTIVES

The main objective of the two Jack Mackerel SNP 2011 Workshops was to contribute to update a diagnostic useful for fishery management and for scientific research. Furthermore the diagnostic can also be useful for internal management in the fishing companies currently producing food for direct human consumption as well as to constitute a technical support to the Peruvian delegation to SPRFMO.

The specific objectives were as follows:

a. To describe the environmental scenario at early 2011 and its relationship with the availability of JM.
b. To calculate volume of catches and CPUE[15] between January 16 (when the fishing season started) and May 20 (agreed date to perform the second workshop), as well as to calculate the possible overall production including catch and discards.
c. To measure the size structure of catches.
d. To describe the relationships between catches and environmental parameters.
e. To analyze changes in distribution and abundance of JM using acoustic and geostatistic methods.
f. To describe the possible scenarios for the following months.
g. to evaluate the methodological feasibility and cost of using acoustic data from fishers (Gerlotto et al., this meeting).

## 4. MATERIAL AND METHODS

### 4.1. Fishing vessels

Peruvian fleet includes 34 vessels operating acoustic systems of Level 2[16] according to the document of reference 8. These vessels can produce data on: (1) calibration using spheres; (2) fish aggregation typology and biomass calculations; (3) noise and target strength measurements; (4) zooplankton abundance calculations; (5) measurement of depth of thermocline (6) prey-predator interactions observation; (7) seabird and marine mammals observations; (8) biological sampling.

Table 1 List of the main echosounder and models operated by vessels of the different fishing companies (in number of vessels)

| Company | SIMRAD | FURUNO | FREQUENCY (kHz) |
|---|---|---|---|
| Austral | 2 ES60s | | 120 |
| Copeinca | | 4 FCV-30s | 38 |
| Diamante | 5 ES60 | | 120 |
| Hayduk | 8 ES60 | 1 FCV-30s | 38 |
| P.Pacífico | 1 ES70 | | 120 |
| TASA | 13 ES60 | | 120 |
| Total | 29 | 5 | |

[15] CPUE: Catch Per Unit of Effort
[16] Level 2 consider the fishing vessels using at least a digital ecosounder and one split beam transducers. Level 1 correspond to vessels operating digital echosounders and at least 2 split beam tranducers.

### 4.2. Acoustic data, algorithm and post-processing

For the purposes of the workshops we used files of RAW[17] data format collected by 15 ES60 echosounders. Digital echograms were continuously recorded during all fishing trips since January 13, when the fishing season began. Data were stored in external hard discs after every trip finishes. The used software was Echoview[18].

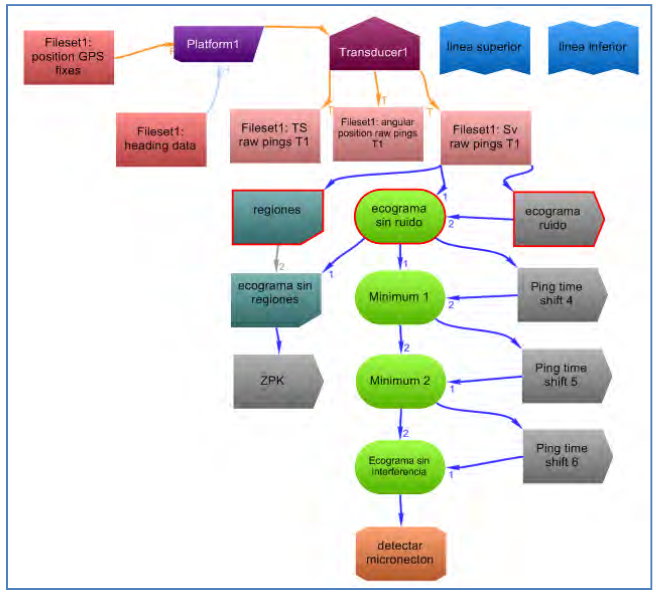


Fig.6. A virtual algorithm designed in Echoview to harmonize, remove noise and interference. Depending on the degree of interference one among 3 options can be chosen. Clean echogram can be obtained after thresholding to produce echointegration of zooplankton if needed.

Post-processing of echograms also implies to execute a semi-automatic detection of fish schools. The assignation of identity is based, (i) on the experience of the operator to identify echotraces, (ii) on the results of fishing sets. The detected schools are exported from the cleaned echogram to databases to produce biomass calculations in worksheets (Excel, MS Office) and distribution charts (Surfer, Golden Software). The ping rate was standardized to one per second, then all Elementary Sampling Distance Units (ESDU) of 0.5 (January-March) and 1.0 n.mi. (March-May) were normalized to 180 or 360 pings depending whether less than or more than those values were observed respectively in order to reduce a bias in the echointegration. The methodology is presented by Castillo et al[19] (2011).

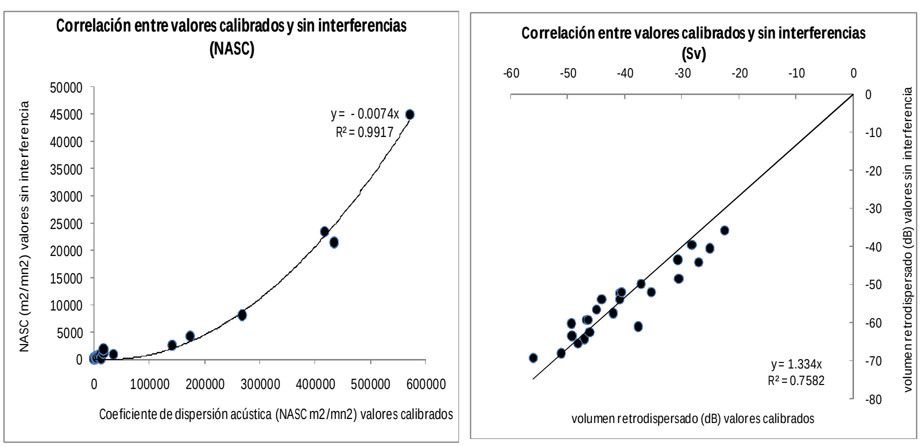


Fig. 7. The calibration of a single vessel (TASA 419) was used as a reference. The by default transducer Sv gain was set in 26.5.0 dB; the calibrated value was calculated and set in 26.43 dB. The small difference made no necessary to correct NASC values (Nautical Acoustic Scattering Coefficient, m2/mn2). However, for those cases where the data was contaminated by interference (e.g. other sounders or sonar of the same vessel) it is possible to apply

[17] RAW data format is the by default structure of SIMRAD (Kongsberg, Norway) telegrams.

[18] Echoview is a trademark by Myriax (Tasmania, Australia).

[19] Castillo P.R., S. Peraltilla, A. Aliaga, M. Flore, M. Ballón, J. Calderón y M. Gutiérrez. 2011. Protocolo técnico para la evaluación acústica de las áreas de distribución y abundancia de recursos pelágicos en el mar peruano, Versión 2009. En Inf. Inst. Mar Perú Vol.36 Nros.1-2, pag 7-28.

correction factors. Therefore we exported the calibrated values and compared to the ones not calibrated but cleaned. It was found a correction equation (1E-07 $NASC^2$ - 0.0074 NASC ; $r^2$=0.9917) for NASC, and 1.334 ($r^2$=0.75) for the backscattered energy (Sv, dB).

### 4.3. Calibration and noise measurement

The high number of vessels made no possible to calibrate all the echosounders although the by default settings were similar. Furthermore the software of the ES60 does not permit to calibrate the echosounder, then this was made experimentally from Echoview for a single vessel (FB Tasa 419) extrapolating the correction for all the other ones. See Fig. 7 for details. The noise measurement was made in Echoview by matching the Sv Raw Echogram into a virtual variable, then noise was removed as indicated in Fig.6.

### 4.4. Used data

The used databases were collected and built in compatible formats regarding the ones used by IMARPE:

- Fishing sets, by species, date and georeferenced.
- Landings by species and date.
- VMS data, by date.
- Length data by species, landing and date.
- Acoustic logbook, by species, date and georeferenced in ESDUs of 0.5 and 1.0 n.mi.
- Satelital oceanography data.

### 4.5. Other methods

Other methods used during the workshops are published in available volumes about study, monitoring and assessment of fishing resources (e.g.: Rivoraird et al 2002[20], Bez & Rivoraird 2001[21], Simmonds & MacLennan 2005[22], Sparre et al 1990[23], Simmonds et al 2009[24]). Therefore obtained results correspond to standard procedures which are verifiable.

- Environmental data: they were used daily NOAA databases on sea surface temperature. The thermal pattern of IMARPE was used to calculate local anomalies. T-S diagrams were used to describe the type of water masses in which JM distributed.

[20] Rivoraird J., J. Simmonds, K.G. Foote, P. Fernandes & N. Bez. 2000. Geoestatistics for estimating fish abundance. Blacwell Science.

[21] Bez N., J. Rivoraird. 2001. Transitive geostatistics to characterise spatial aggregations with diffuse limits: an application on mackerel ichtyoplankton. Fisheries Research 50 (2001) 41-58

[22] Simmonds J.E., D.N. MacLennan. 2005. Fisheries Acoustics, second edition. Blackwell Science.

[23] Sparre P., S. Venema. 1997. Introducción a la evaluación de recursos pesqueros tropicales. Parte 1, Manual FAO. Documento Técnico de Pesca N°306, 420 pp.

[24] Simmonds J.E., M. Gutiérrez, A. Chipollini, F. Gerlotto, M. Voillez & A. Bertrand. 2009. Optimizing the design of acoustic surveys of Peruvian anchoveta. ICES Journal of Marine Science Advance Access published April 30, 2009

- Size structure: It was graphically observed the weekly sequence of length data in order to analyze the modal progression of the cohorts for JM and relate them to age.

- CPUE: it was used the duration of every trip and the catches obtained in order to analyze their fluctuation in time.

- Measurement of the abundance based on geostatistics methods: They were classified the fishing grounds by their closeness to seven zones defined by reference points (Paita 5°S, Parachique 6°S, Chicama 7°S, Chimbote 9°S, Supe 11°S, Callao 12°S y Pisco 14°S). The weekly mean catch in every zone was assumed as local density.

  To study the changes in the geographical distributions of JM we estimated both the position of the Centre of Gravity (CG) and the related inertia. In 2D, the CG, which represents the mean location of the population, is a vector with two coordinates. The inertia, whose units are surface units (typically $nmi^2$), quantifies the spatial dispersion of the population around its CG. The following equations are used to calculate the centre of gravity (CG) and the inertia (I):

$$CG = \begin{bmatrix} CG_x = \frac{\sum_{i=1}^{n} x_i z_i}{\sum_{i=1}^{n} z_i} \\ CG_y = \frac{\sum_{i=1}^{n} y_i z_i}{\sum_{i=1}^{n} z_i} \end{bmatrix} \qquad I = \frac{\sum_{i=1}^{n} \left[ (x_i - CG_x)^2 + (y_i - CG_y)^2 \right] z_i}{\sum_{i=1}^{n} z_i}$$

  with (Xi,Yi) as the location of sample i for i = 1 in n with n the total number of samples and Zi the NASC value of the sample at this point. All calculations were performed in orthodromic distances.

  To calculate the geoestatistic abundance the mean inertia (I) and mean catch per fishing set (C) was calculated weekly for each area and used as a proxy of density, then abundance (A) is obtained as:

$$A = I \, . \, C \qquad (t)$$

- To calculate the acoustic abundance they were averaged the NASC values by fortnights and statistic squares of 6 by 6 minutes of latitude/longitude (approximately 36 $mn^2$ each of area (S)). The used TS-Size relationship was 20*log(L)-69 (dB) which is a standard equation for JM[25], then scattering cross section (σ) was derived. The Size-Weight relationship (w) was obtained from the biometric data. The fish density was calculated for every ESDU by dividing the echointegration (NASC) by σ. The abundance (B) was obtained using the next equation:

$$B = \frac{NASC}{\sigma} \cdot S \cdot w \qquad (t)$$

- Structure of the distribution of JM: throughout calculation of statistical variograms to catches and acoustic NASC it was posible to measure the diameter of JM clusters.

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25 Lillo S., J. Córdova, A. Paillaman. 1995. Target Strength measurements of hake and jack mackerel. ICES Journal of Marine Science, 53: 267-271.

## 5. RESULTS and DISCUSSION

### 5.1. Environment conditions and Jack Mackerel distribution

During January 2011 the thermal conditions were cold (-2°C of anomaly as an average inside the first 50 n.mi. from the coast) in the northern Peru. A high secondary production was observed (zooplankton, dominating the Euphausiids, the main item in the JM diet). In that zone the fishing season started on January 16. During the 4th fortnight (February 15 to March 1) we detected a sudden but temporal warming which was followed up by a strong upwelling. However the fishing grounds in the northern region remained rather stable until the 6th fortnight (March 17 to 31) when fishing grounds were detected closer to Chimbote and Callao. The fleet abandoned Northern Peru but it remained unclear whether the JM distributed in that area also moved further south

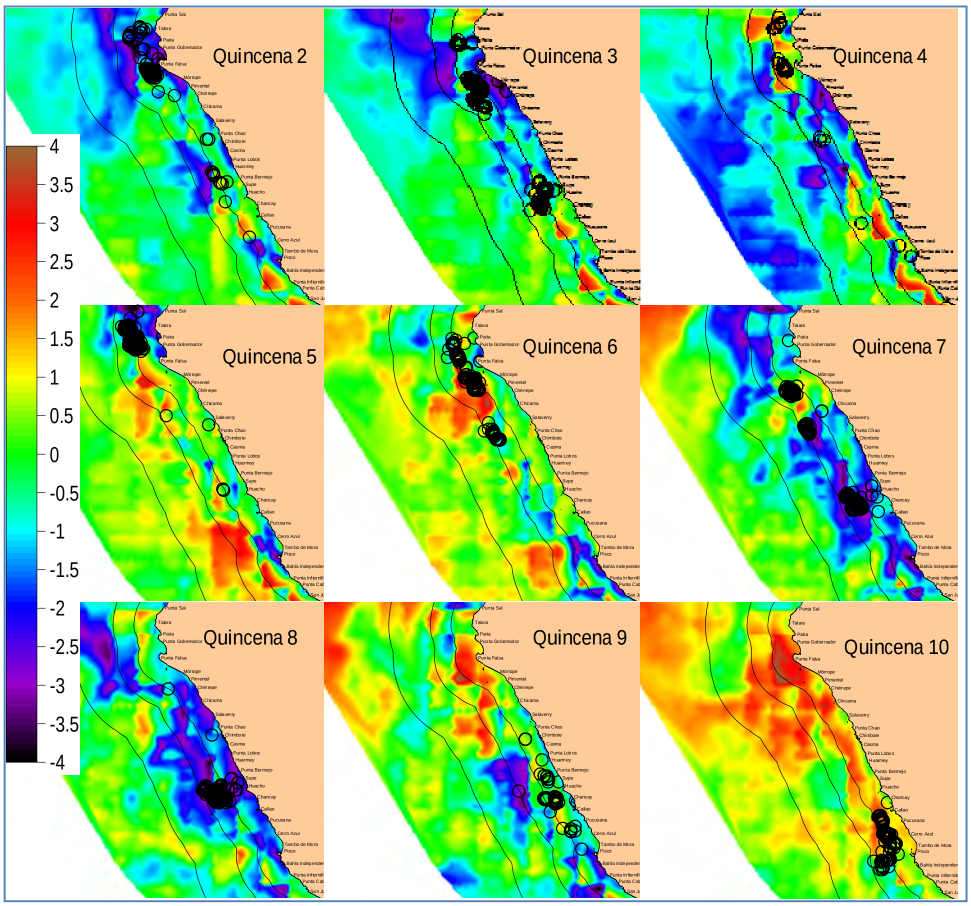


Fig. 8. Apparent progression of JM catches since 2th to 10th fortnights (January 16 to May 20) following up the influx of thermal anomalies in the same time period (graphic scale to the right, in Celsius degrees). Fishing sets are indicated by black circles. The arrival of a Kelvin Wave is clearly observed during the 9th fortnight, and apparently forced a change of distribution of JM further to the south.

During the 9th fortnight (May 1 to 15) it was clear the arrival of a Kelvin Wave over all the northern Peru, and apparently dispersing anchovy and forcing JM to distributed further to the south during 1oth fortnight (May 15 to 30 de mayo). Fig. 8.

Analyses were performed to relate oceanic parameters to the changes in distribution of JM in order to explain the variations on its availability. As one of the numerous results we obtained a T/S (temperature/salinity) relationship to describe the type of water masses in which JM inhabits, then it was found that JM moved from an oceanic front between ACF and AES (in the northern Peru) toward a other front, this time characterized by ACF and ASS (in the central Peru). (Fig. 9).

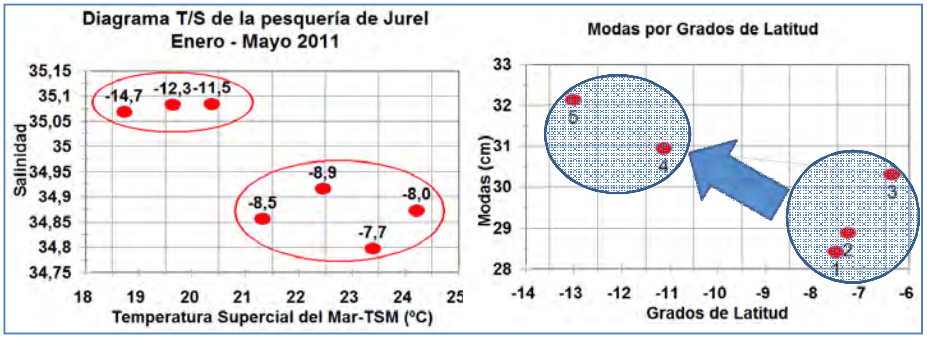


Fig.9. Since January to May the fishing effort had been performed in two well defined zones from the point of view of the relationship Temperature-Salinity (T/S). In the upper-left part of the graphic to left it is observed (Y-axis) the typical salinity of the ASS borderlines with relatively low temperatures, which correspond to latitudes between Chancay (11°30'S) and Independencia Bay (14°45'S). In the same graphic though on its right-low corner, it is characterized a zone with mixed water between ACF and AES with relatively high temperatures between Chicama (7°30'S) and Chimbote (9°S). In the right side graphic they are observed this two well delimitated areas, in this case related to the modal progression of JM.

This is the first time when it has been possible to document in short time intervals the influence of environmental conditions and the plasticity[26] of JM in Peru, which also constitutes an opportunity of analysis of the several existing hypothesis on number of stocks, migrations and metapopulations. However, in future analysis should be also considered the details of vertical habitat and the relative concentration of preys (zooplankton).

## 5.2. Catches, CPUE and by catch

Between January 16 and May 20 the fishery caught 102,415 t (non official numbers). 95,129 (92.88%) corresponds to JM, and 7,286 t to Mackerel (7.12%). Fig.10 shows the catches by weeks and months.

| SEMANA | 2 | 3 | 4 | 5 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | TOTAL (t) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JUREL (t) | 255 | 1,064 | 11,736 | 11,575 | 8 | 13,446 | 11,944 | 8,304 | 1,060 | 8,913 | 6,144 | 2,971 | 6,406 | 1,481 | 3,360 | 4,120 | 2,344 | 95,129 |
| CABALLA (t) | 11 | 26 | 667 | 407 | 22 | 1,429 | 1,006 | 226 | 0 | 192 | 11 | 19 | 659 | 1,349 | 500 | 515 | 246 | 7,286 |
| Total (t) | 265 | 1,090 | 12,403 | 11,982 | 30 | 14,875 | 12,950 | 8,530 | 1,060 | 9,105 | 6,155 | 2,990 | 7,065 | 2,830 | 3,860 | 4,635 | 2,590 | 102,415 |

| MES | ENERO | FEBRERO | MARZO | ABRIL | MAYO | TOTAL (t) |
|---|---|---|---|---|---|---|
| CABALLA | 747 | 662 | 2,534 | 2,082 | 1,262 | 7,286 |
| JUREL | 15,046 | 11,345 | 37,846 | 21,068 | 9,823 | 95,129 |
| TOTAL | 15,793 | 12,007 | 40,380 | 23,150 | 11,085 | 102,415 |

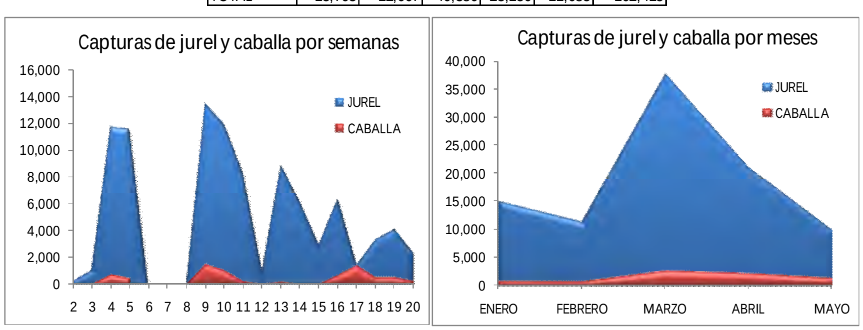


Fig. 10. Weekly catches of Jack Mackerel and Mackerel (*Scomber japonicus*). The lack of catches between weeks 6 and 7 is due to the fact that provided quota had been reached up. The decrease in catches since March is due to the start of the anchovy fishing season (most of vessels leaved the JM fishery).

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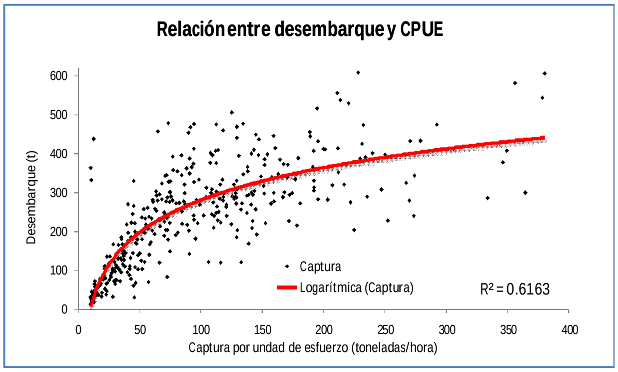
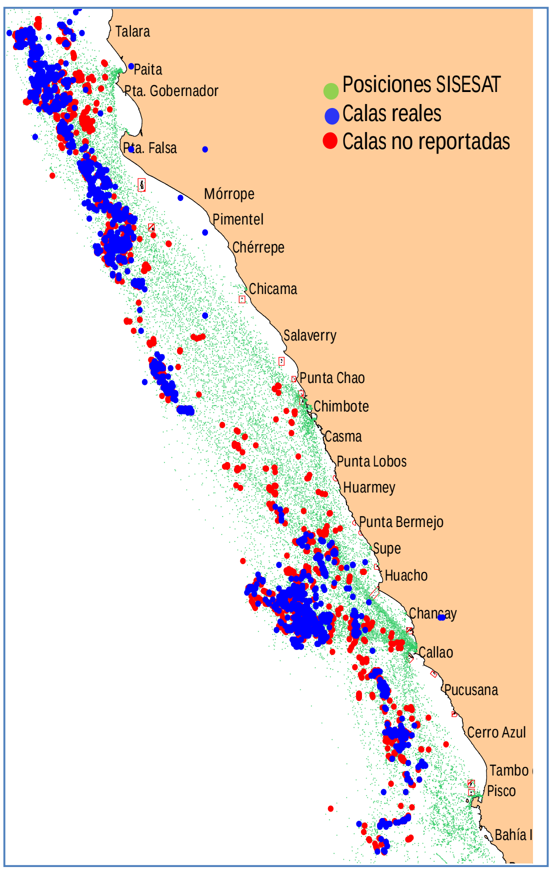
[26] Bertrand A., M. A. Barbieri, F. Gerlotto, F. Leiva, J. Cordova. 2006. Determinisms and plasticity of schooling fishing behavior as exemplified by the south pacific Jack Mackerel Trachurus murphyi. Mar Ecol Prog Ser . Vol 311: 145-156.




CPUE showed a positive relationship with landings (459 arrivals from January 16 to May 20). The average rate of change in CPUE from one week to the next fluctuated between 1.0 and 1.25, then catches tended to be progressively bigger. This is explained by the progressive closeness of fishing grounds regarding the main landing points. Mean CPUE was set in 79.03 t/h, and the average landing was 207.25 t per trip.

Fig.11. Relationship between catch per trip (t) and CPUE (t/h) as a proxy of abundance of Jack Mackerel. Higher values of CPUE are related to catches produced in the vicinity of Paita and Callao harbors.




Using VMS data it has been possible to calculate the number of fishing sets which could have been discarded due to the presence of species which catch is not allowed (King gar, skipjack, black skipjak, giant squid etc).

1,422 fishing sets were reported between January 16 and May 20. The VMS data was filtered to select points were the speed stood in a range from 0 to 0.5 knots in no more than 3 consecutive reports, and where the distance between the first and third report did not exceed 1 n.mi. was After this filtering we found 1,709 possible fishing sets, then a difference of 15% in number of event. Assuming a mean catch per set of 30 tons (which arbitrarily corresponds to first quartile of the observed catch range) we got 8,617 t of by catch , which would have been discarded. Taken into account the current efforts of the Peruvian government for incrementing the direct human consumption of marine food it should be recommended to modify the pertinent laws in order to reduce the problem of the lack of regulations.

Fig. 12. Distribution of reported fishing sets (blue points) and possibly discarded (red points) during January 16 to May 20. It has been evidence of other species whose fishery is not regulated (King Gar, Skipjack, Black Skipjack etc). Green points are reported by the VMS.

### 5.3. Size structure

The size structure observed for JM shows a strong single cohort although by early May new modal group appeared. It is hypothesized that modal groups of juvenile fish (< 22 cm) were distributed inside the first 10 n.mi. from the coast, which is a region where the industrial fleet is not allowed to operate.

It was not possible to get information on fish length from that zone. The only consistent information regarding the catch of JM inside that zone by the artisan fleet indicated that total catch between January and May reached up to 2 thousand tons. The catches of the artisan fleet should be sampled as closely as so is the industrial fleet. It is also important that from now on the fleets cooperate actively with IMARPE performing samplings using nets for collecting egg and larvs of fish. This should be organized and will conduce to a better understanding of the status of JM.

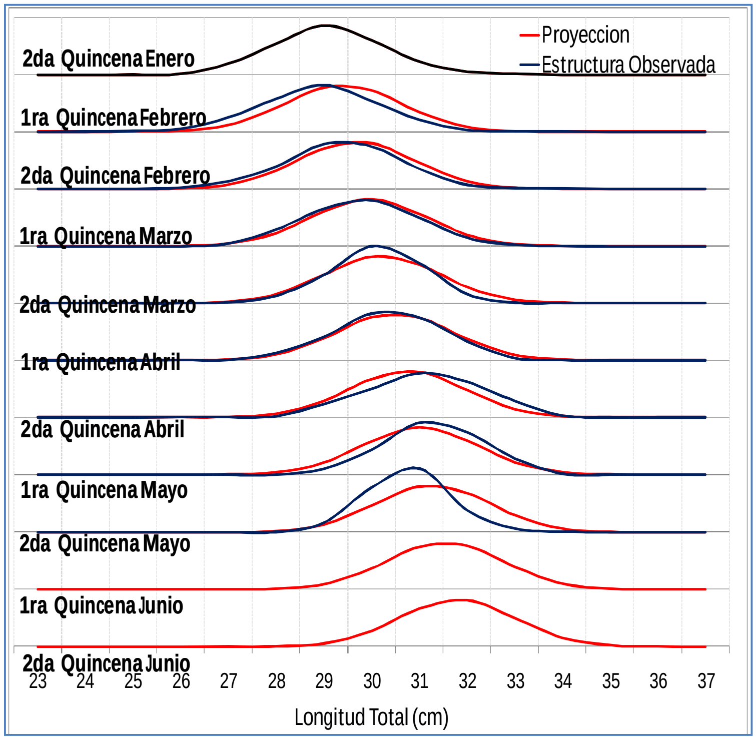



Fig.13. Modal progression of size of Jack Mackerel from January to May (black line) and a growth progression in size until second half of June. The sequence lets to observe a single cohort although the appearance of a new group was observed during the first half of May.

## 5.4. Distribution and acoustic abundance of Jack Mackerel

The area of distribution of JM -as measured using the fishing fleet data- varied from 216 $mn^2$ (8th fortnight) to 3,600 $mn^2$ (2th fortnight).

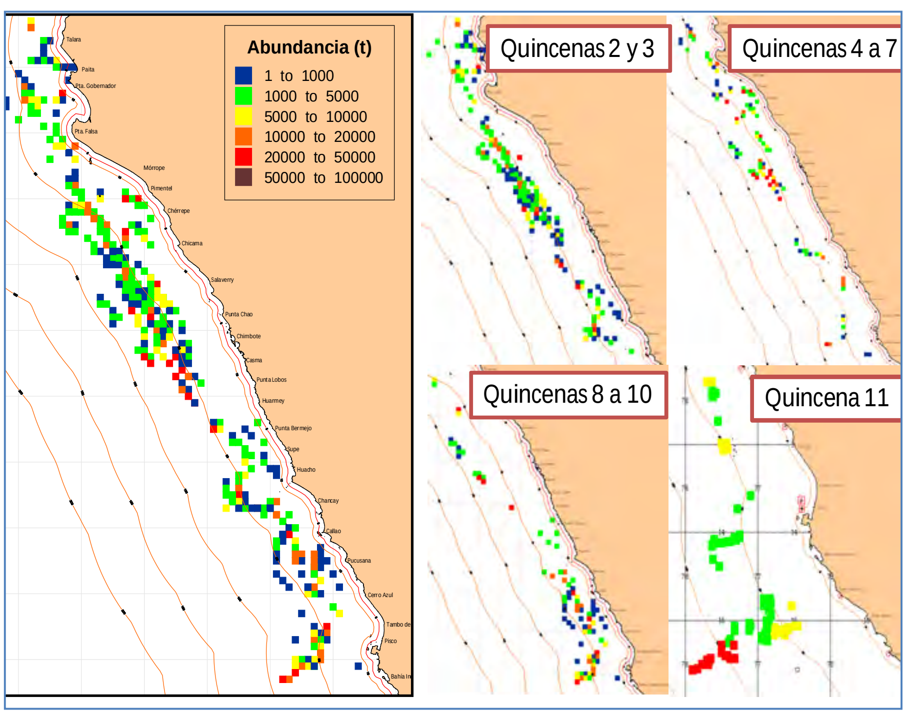



Fig. 14. Cumulative acoustic distribution of Jack Mackerel (left) and relative abundance by statistical squares of 6 by 6 n.mi. To the right is observed the sequence of distribution by fortnights.

This wide difference is due to the growing fishing effort produced since the opening of the season. The fleet made long trips from Callao and Chimbote toward the northern Peru during the first weeks. Also, when the anchovy season started (1th of April) during the 6th fortnight more than 50% of the fleet abandoned the JM fishery.

The acoustic abundance fluctuated between 481,016 t (2th fortnight) and 12,241 t (8th fortnight). The mean abundance was calculated in 300,000 t. The area of distribution has varied from 3,600 to 216 $mn^2$, respectively.

It is worth to notice that acoustic abundance fallen down during the 6th fortnight due to the reduced number of vessels operating. During the 9th fortnight the abundance recovered and increases during the 1oth fortnight as a consequence of new fishing grounds found between 14 and 15°S.

| Quincena | Abundancia relativa (t) | Area de distribución ($mn^2$) | Densidad ($t/mn^2$) | Desviación Estandar (t) | CV (%) |
|---|---|---|---|---|---|
| 2 | 481,016 | 3,600 | 134 | 7,974 | 60 |
| 3 | 460,908 | 3,132 | 147 | 12,402 | 43 |
| 4 | 192,464 | 720 | 267 | 12,674 | 76 |
| 5 | 435,408 | 2,052 | 212 | 10,032 | 76 |
| 6 | 106,640 | 684 | 156 | 10,002 | 56 |
| 7 | 143,992 | 612 | 235 | 9,920 | 85 |
| 8 | 12,241 | 216 | 57 | 3,363 | 61 |
| 9 | 91,797 | 540 | 170 | 8,131 | 75 |
| 10 | 296,956 | 1,800 | 165 | 8,140 | 73 |

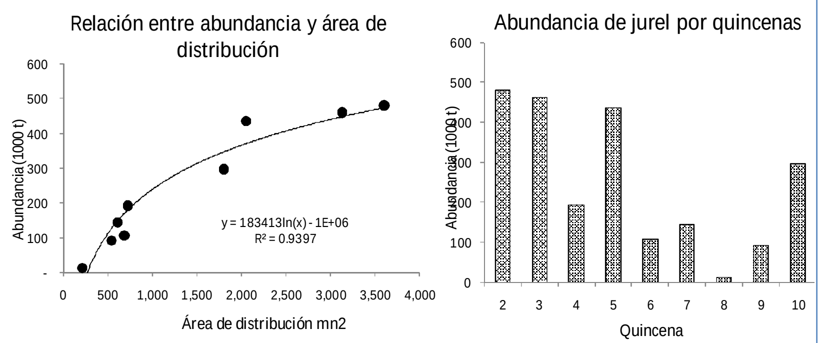



Fig.15. Acoustics estimates of JM abundance by fortnights.

The term 'abundance' is used here instead 'biomass' to relate the calculations to the places where the fleet effectively operated, not to the total distribution area. Abundance has been greater when explored area increased, then possibly approaching the real dimension of the biomass.

## 5.5. **Abundance of Jack Mackerel as calculated throughout geostatistical methods**

When applying this method we assumed that the concept of 'geostatistic inertia' is similar to 'area of distribution' of JM (in relation only with the area effectively surveyed by the fleet). The higher inertia was measured to be 3,923 $mn^2$, while the acoustic area was 3,600 $mn^2$.

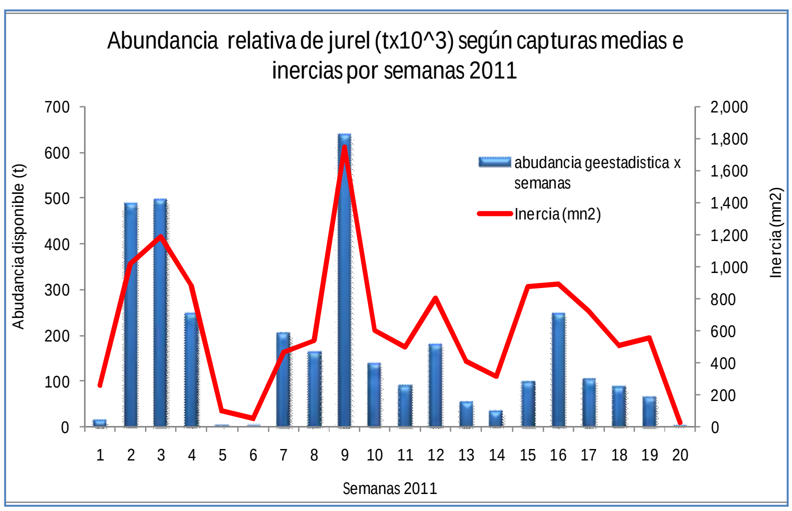



Fig.16. Jack Mackerel abundance (t) as calculated using mean catches as proxy of density by weeks.

The weekly mean abundance was calculated in 168,000 t, with peaks in 639,000 497,000 and 488,000 t. The acoustic estimations showed a mean abundance of 300,000 t with peaks in 481,000 460,000 and 435,000 t.

The standard deviation is high (180,390 t) due to the wide range of measured values, which are in relation to the surveying effort, the temporal closures of fishing grounds, and the change of fishing gears of most of vessels when they targeted anchovy instead JM. In despite the different results it is obvious that the patchy distribution of juvenile JM during past years has conducted to an improved recruitment and to an appearance of a strong year class. Nevetheless the study and monitoring of this important recruitment should be used to test the various existing hypothesis on the number of JM populations, and very specially to analyze possible migration patterns through electronic tagging.

## 5.6. **Structure of the Jack Mackerel distribution**

Exploratory analyses were performed on the representativeness of using the data recorded by digital echosounders during fishing trips. We found that the echointegration generally represents the distribution of fish and preys, and that higher NASC values match with effective detections of JM. Therefore the use of these devices provide useful information for management, for the internal management of the fishing companies, and ecosystem research. Fig.17.

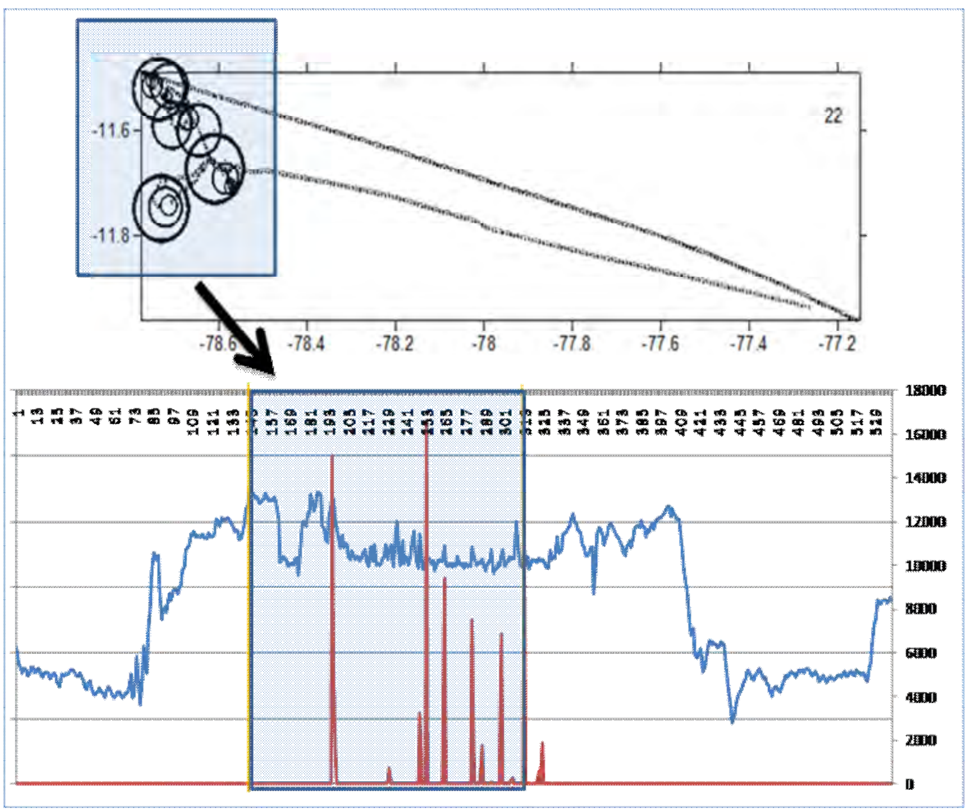



Fig.17.Drawing of one simple track of a single fishing vessel. The top panel displays the vessel route. We can notice that the ship specially surveyed the northwest of its starting point; the black circles are proportional to NASC, which is far higher in the “exploration-exploitation area” (shadowed square). In the bottom panel the same survey is displayedwith the echointegration (Sv) indicated with a blue line. Red bars show the location and biomass (NASC) of the fish schools affectively detected as JM.

Using data extracted from digital echograms recorded by the fleet (25 fishing trips summing 12,305 n.mi. surveyed), and the database of detected JM, it has been calculated a variogram in order to measure the dimension of the JM clusters both in term of catches and echointegration. The results points out that in both cases the length or diameter of every JM aggregation zone was about 3 n.mi. Fig. 18. This is consistent with results published in the literature[27].

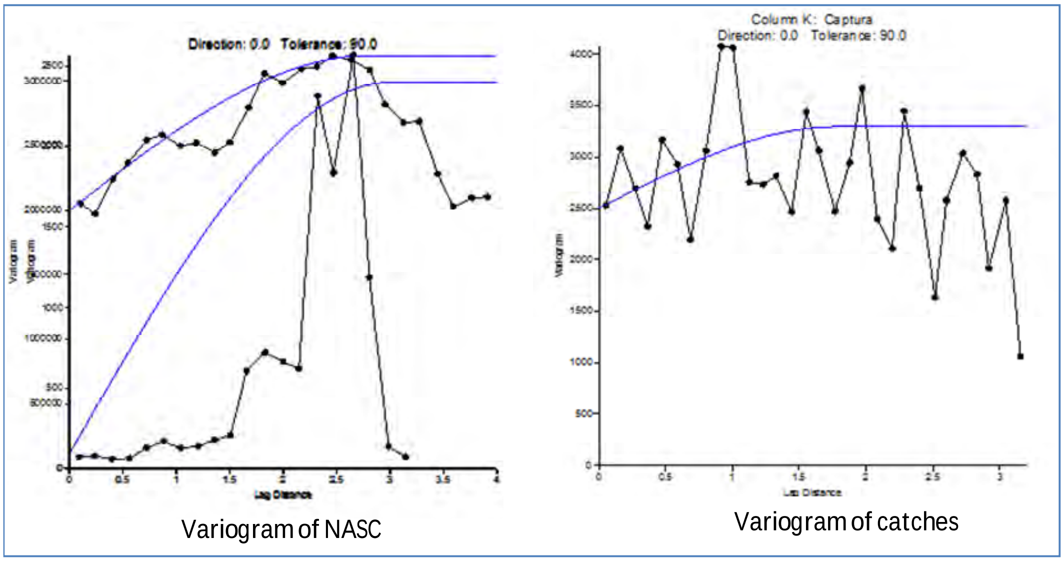
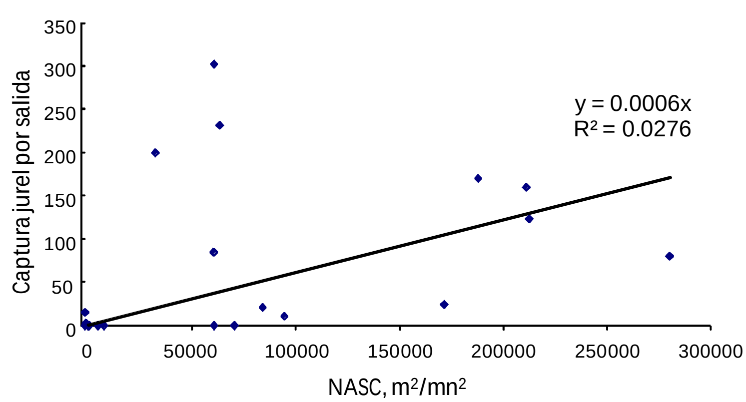



Fig.18. Variograms of NASC (left) and catches of a sample of 25 fishing trips (right). Notice that the number of data used is small compared to ones used for measuring the distribution.

Taking into account that all vessels have operated in all zones, then same data on NASC (X-axes, Fig.19) can be used to infer that there were three defined groups of efficiency: (1) those who get good catches in despite of the fact that did not detect high NASC values (possibly when the fishing ground was already been detected); (2) those whose catches is proportional to NASC (e.g. during the surveying to detect the fishing grounds); and (3) those whose catches are relatively low in despite of having detected high NASC values (which suggests that there ia a lack of surveillance to sonar systems by part of the crew).

Fig.19. Relationship between mean catches and mean echointegration (NASC) per trip. There are three possible groups of behavior: (1) the first correspond to catches obtained when location of fishing ground is already known; then NASC values can be low but catches high; (2) the catches obtained with proportional NASC values; and (3) the low catches in despite of detected high NASC values, which suggest a lack of efficiency when using sonar systems.




[27] Hancock J., P. Hart, T. Antezana. 1995. Searching behaviour and catch of horse mackerel (Trachurus murphyi) by industrial purse-seiners off south-central Chile. ICES J. mar. Sci., 52: 991–1004. 1995

These findings are important because the Skippers' behavior could be affecting the way we use the data of their sounders when calculating the biomass or abundance. It is then necessary to perform deeper analysis before concluding about a underestimation of JM abundance (and about the avoidance effect too in the presence of the vessels). This might be valid for the Peruvian EEZ and high seas fleets. Fig. 19.

### 5.7. Possible scenario for the second half of 2011

Since early June a Kelvin Wave sinked the thermocline along Peruvian coast and provoked a disturb n the distribution and catchability of anchovy, which distributed deeper and disperse closet o the coast. Following up the same influx JM (and Mackerel) clusters changed its distribution to get closer to the coast and moving toward the south. This perturbation ceased by early August.

It is during September to October when the dispersion of JM increases while the coastal anchovy ecosystem growth toward the west, making JM to distribute far from the coast (winter windy time). Having this in mind the most possible distribution area for JM during those months would have to be toward the region with the weakest influence of coastal cold waters. When this report was being drafted (by early September) the fishing operations were again changing from south to north and farter from coast in the central part of the country (11-12°S). When the winter time ceases JM would again being distributed closer to the coast.

## 6. CONCLUSIONS

- The relatively high JM abundance during 2011 would be the product of a successful spawning occurred during the second half of 2007. It matches the observation made in Peru during the past 3 years when incidental catches of (juvenile) JM were made during anchovy fishing seasons. Also the artisanal fleet has been catching juvenile JM along the Peruvian south coast with growing fish length. This supports the hypothesis of a Peruvian stock and/or a Peruvian metapopulation.
- The current availability of JM, relatively close to the coast, contrasts with the patchy distribution during the past years, and it would be related to the confluence of cold conditions along the coast, high primary and secondary productivity along the shelf break, warmer temperatures in the vicinity and a sinking of the oxycline, which created a narrow zone of mixed waters and a good vertical habitat where JM aggregated.
- After 10 years the accessibility to JM started in the northern Peru revealing its plasticity and a change in the pattern of its displacements along the coast.
- The current abundance of JM is observed in a strong single cohort ranging from 27 to 32 cm, and has been assessed in 425,000 t. However this calculation is only representative of the zones where the fleet operated. Then it does not necessarily reflect the true structure and population level of JM within the Peruvian EEZ.
- The total length ranged from 23 to 37 cm, and evidence exists from the artisan fishery regarding the distribution of juveniles inside the first 10 n.mi. where the industrial fleet cannot operate, while fish above 37 cm could be distributed in more oceanic zones.
- It has been calculated in 15% the volume of discarded fish compared to the total catch since January to May. It represents a waste of about 8,617 t of species that could perfectly been devoted to direct

human consumption. These species were: king gar, skipjack, black skipjack, giant squid, bonito and others.

## 7. RECOMENDATIONS

- To promote the use of information collected by the fishing fleet in order to perform direct assessments of JM and others. A Fisheries Acoustics Working Group should be created, with participation of scientists from SPRFMO countries.
- To propose to IMARPE and SPRFMO the development of a cooperative research about monitoring and study of JM and other species which straddle their distribution with the Peruvian EEZ. This should include the collection of fish eggs and larva using biological net and fishing gear specially designed for pre-recruits aboard the Peruvian fishing fleet. It must also be considered the possibility of an electronic tagging of JM in the frame of the JMRP.
- To collect and update the databases on catches and biometrics of JM including the artisan fishery in order to get a more accurate diagnostic of the JM Peruvian stock throughout the models currently developed by SPRFMO.
- During the fishing season they have been produced by catches and discards of still not authorized species, or species without commercial value. Both the Peruvian government and SPRFMO should produce specific regulations in order to start the creation of a legal framework for species currently unexploited and/or unregulated.

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