



Jack Mackerel (*Trachurus Murphyi, Nichols, 1920*) acoustic survey in the central coast of Chile

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Abstract

Acoustic surveys have been carried out by IFOP since 1991 in the central zone off Chile. These surveys were carried out in autumn, in order to determine the distribution and biomass of jack mackerel. Between 1997 and 2002, the analysis area was delimited dynamically, considering the jack mackerel distribution in the survey time. In this period, the surveys were done inside the EEZ.

Since 2003, the jack mackerel distribution was more distant to the coast and with a trend to the south, extending the analysis area to 400 nautical miles (nm) from the coast. This situation determined two steps in the survey protocol; first, an area exploration with industrial vessels in perpendicular transects each 25-30 nm. Second, it considered an acoustic survey in order to estimate the biomass in the identified area. The acoustic information (Sa and TS) was registered each 0.5 nm. The results show variations in the space used by this resource, with important changes in the biomass and its distribution.

1. Introduction

The jack mackerel distribution and acoustic biomass estimated by IFOP since 1991 has been employed for two main purposes: learning about the migration patterns and knowing the biomass level in the main fishery zone (Figure 1). The acoustic biomass is the most important index of abundance employed for stock assessment purposes. Its spatial and temporal variations have permitted developing different hypotheses related to its population status.

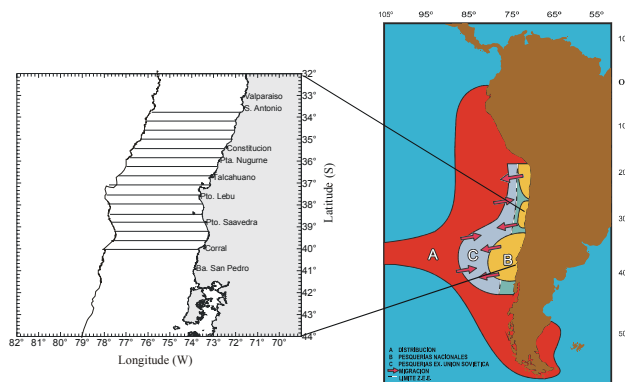


Figure 1.- Geographical distribution of *Trachurus murphyi* in the el Southeastern Pacific and survey area.

In the EEZ, important changes in the abundance of the resource have been observed between 1997 and 2007, increasing the estimated biomass from 3.2 million tons in 1997 to 5.97 in 2001. After that, it decreased, reaching 91,000 tons in 2007. Since 2002, records of the fishing fleet show the presence of an important area of concentration of the resource out of the EEZ, for which, an extension of the western limit of the evaluations to 400 nm was necessary.

In view of the high operation costs of the vessels used in the acoustic survey, the wide area of distribution of the jack mackerel, and in order to use the available vessel days efficiently, the surveys are conducted in two stages since 2003. In the first stage, an acoustic exploration (7-9 days) is carried out by purse-seine fishing vessels using echosounders and sonars to obtain relative index of abundance, before the conduction of the acoustic survey to improve the efficiency in the use of the sampling capacity, given the extension of the evaluation area and the limited available resources (days/ships). This has allowed getting to know important changes in the availability of the jack mackerel inside and outside the EEZ off the central zone from Chile.

2. Materials and Methods

The acoustic surveys were carried out in the R/V "Abate Molina", property of the Undersecretariat for Fisheries, together with purse-seine vessels that operate in the Chilean jack mackerel fishery. The fishing vessels are called to take part by means of a notice published in the regional press, the requirements considering the meteorological conditions present in the study area are: lengths superior to 50 m, fishing hold over 700 m³, minimum speed 12 knots, and vessels equipped with echosounder (SIMRAD EK-60), split beam transducer of 38 KHz, sonars and mid water trawls. The operation costs of the participating vessels are financed by a fishing quota allocated for research, which is different from the annual quota assigned to the companies. The

acoustic exploration was carried out only with purse-seine vessels that operate in the Chilean jack mackerel fishery, which are called to take part and financed similarly to the acoustic survey.

The area of study which includes from south Valparaiso (33°20'S) to Corral (40°00'S), between the coast and the 200 nm limit, for the period 1997-2002 (Figure 2a); while, from 2003 to 2007, the 200 to 400 nm sector is incorporated, extending the area of study near Chiloe (Figure 2b and 2c).

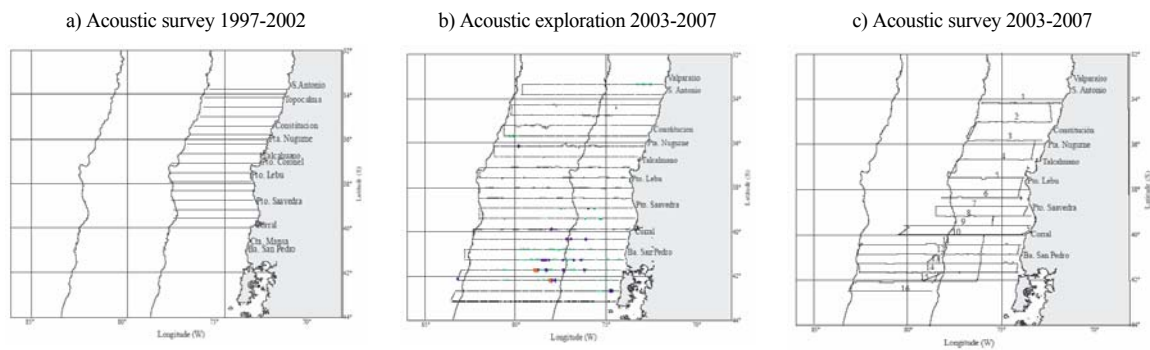
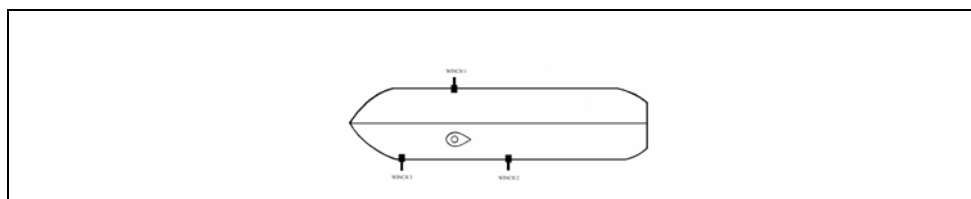
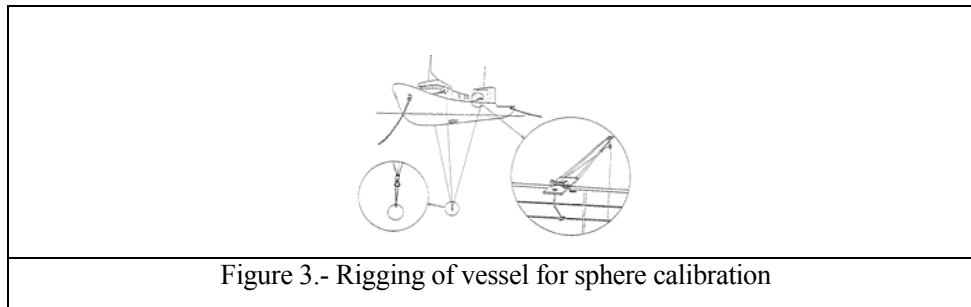


Figure 2.- Grid of track for acoustic explorations and survey

The evaluation strategy was adaptive in space and time (Barbieri *et al.*, 1996). That is, on one hand, that the area of study was adjusted to include sectors where the fleet was operating before the acoustic survey, and, secondly, the cruise period was in autumn, when the purse-seine fleet of the center-south zone reached the maximum values of catch per unit effort (CPUE). Since 2003, the adjustment also considers the information of the distribution obtained in the acoustic explorations carried out 20 days before the acoustic survey, collecting information on the characteristics of the aggregations (type, number, height, length and depth) and the level of abundance, in agreement with the expert judgment of the fishing officials ("low" from 1 to 20 tons, "medium" between 21 and 200 tons, and "high" more than 200 tons).

Before the cruise, the echo sounder Simrad EK-500 of the R/V "Abate Molina" and Simrad EK-60 from the purse-seiners were calibrated in agreement to the protocols established by the manufacturer (SIMRAD, 1991). The calibration consists of an iterative process that measures the intensity of the target strength (TS) and echo integration (S_v) from a standard target (copper sphere of 60 mm diameter) of known target strength, located in the center of the acoustic beam (Figure 3)





The process of TS measurement and the adjustment of the gain of the echo integration system are carried out by means of the following expressions:

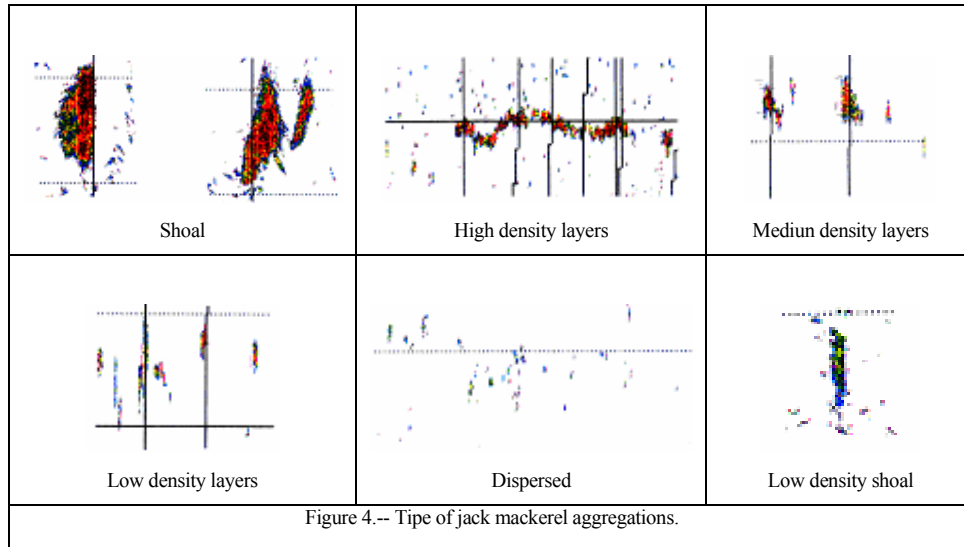
$$G_1 = G_0 + \frac{TS_m - TS_t}{2}$$

Where:

G_1 is the new gain of the transducer (dB), G_0 is the transducer old gain (dB), TS_m is the measured target strength intensity (dB), and TS_t is a theoretical target strength intensity (dB).

A sampling design with equidistant transects perpendicular to the coast, with a separation of 25 nm, was applied (Figure 2a and 2c), increasing the separation in the north (ZEE) for the low presence of jack mackerel, and keeping the standard area assessed from 1997 to 2002. Considering the recommendations of Barbieri *et al* (1996) and MacLennan & Simmonds (1992), a systematic design has been employed for assessing the biomass and distribution of jack mackerel.

The classification of the aggregations was: shoal, high density, medium density, low density layers, dispersed and low density shoal (Figure 4). The species identification from the acoustic echograms was realized by two methods. The first consists of the analysis of the echo traces by considering the jack mackerel behavior and the coefficient backscattering volume (S_v), applied the formulation given by SIMRAD and the methodology developed by the Unit of Acoustics of IFOP (Guzmán *et al*, 1983). The second is the interpretation of echograms joint to the mid water fish catch. This information is complemented with the catch of the purse-seine fleet, when they coincide in space and time with the development of the cruise. With this respect, the scanty fauna associated to this species and the identification trawls reduce the bias for eventual mistakes in the assignment of species.



The acoustic information is the value of average density, expressed in the volume of backscattering in a nautical square mile (Sv), and the values of intensity of target strength (TS) of jack mackerel detected inside the integration limits of the sampling basic unit. The spatial distribution of the this species in the area is plotted as a contour chart (Software Surfer 8.0), where the curves join equal density points, allowing to emphasize the areas of major concentration of the resource (MacLennan and Simmonds, 1992).

The jack mackerel biomass was estimated as the product of the area distribution of jack mackerel in nautical square miles (A), mean density of the integration units (Sa) in the distribution area (\hat{Z}_v), average weight of the jack mackerel in the area (\bar{w}) and mean target strength (\overline{TS}) in decibels.

$$\hat{B} = \frac{A * \hat{Z}_v * \bar{w} * 10^{-3}}{4 * \pi * 10^{10} \frac{\overline{TS}}{10}}$$

and

$$\hat{Z}_v = \frac{1}{V} \int Z(x) dx$$

The target strength (TS) was calculated from the regression model $TS = 20.11 \cdot \text{Log}(L) - 68.67$, determined by Cordova *et al.*, 1998. The model adjusts to a quadratic relation between the length and the target strength (Foote, 1986).

The variance of the biomass was estimated by a variogram, which measures the average variability between two experimental measurements $(Z_{(xi)} - Z_{(xi+h)})^2$ as a function of its distance h (Petitgas and Lafont, 1997), defined by means of the equation:

$$2\gamma(x, h) = E[Z(x) - Z(x+h)]^2$$

The precision level for these estimates was expressed by the coefficient of variation (CV).

3. Results/ Discussions

The acoustic surveys carried out between 1997 and 2007 showed that the number of aggregations (number/nautical miles) decreased since 8 to 2 (Table 1), and an increase of fork-length from 24 cm to 32 cm in 2006 (Córdova *et al.*, 1998-2008). This growth in length also was observed in the samplings collected from the fishery.

Table 1. Number of aggregations (%) of jack mackerel for nautical mile

Years	Number of aggregation for nautical mile (%)							
	1	2	3	4	5	6	7	8
1997	52,3	25,4	11,5	5,5	2,6	2,0	0,3	0,2
1998	63,2	22,1	9,5	2,2	2,2	0,7		
1999	69,5	20,9	6,4	2,5	0,6			
2000	70,8	17,4	10,0	13,0	0,4			
2001	71,4	25,98	2,7					
2002	93,1	6,9						
2003	87,6	12,4						
2004	85,0	15,0						
2005	92,3	7,7						
2006	91,8	8,2,						
2007	95,2	4,8						

With this respect, changes in the use of the space by the jack mackerel are also observed since 2003. Spatial distribution of the resource (Figure 5) of the acoustic explorations shows changes in the centers of gravity towards the south of the area of study (Barbieri *et al.*, 2003-2005 and Bahamonde *et al.*, 2006). This is confirmed by the centers of gravity estimated for the acoustic surveys carried out later in the zone, demonstrating stability in the distribution of the aggregations

of jack mackerel (Figure 6). It is important to point out this aspect, since this pelagic transzonal species presents important mesoscale movements, like the displacement (N-S; E-W) across the west drift current (Grechina, 1998), suggesting this stability between the acoustic exploration and the development of the acoustic survey a permanency of the resource associated to feeding activities in the area of study.

The presence of the resource outside the EEZ registered in the acoustic exploration previous to the acoustic survey is also observed in the magnitude of the abundance estimated inside and outside the EEZ, registering the first 200 nm a strong decrease on the acoustic estimation, from 5.97 million tons in 2001 to 91,000 tons in 2007; while outside the EEZ, the levels increase from 1.759 million tons in 2003 to 3,04 million tons in 2007, showing that the spatial distribution of the jack mackerel is withdrawing off the coast of Chile (Table 2).

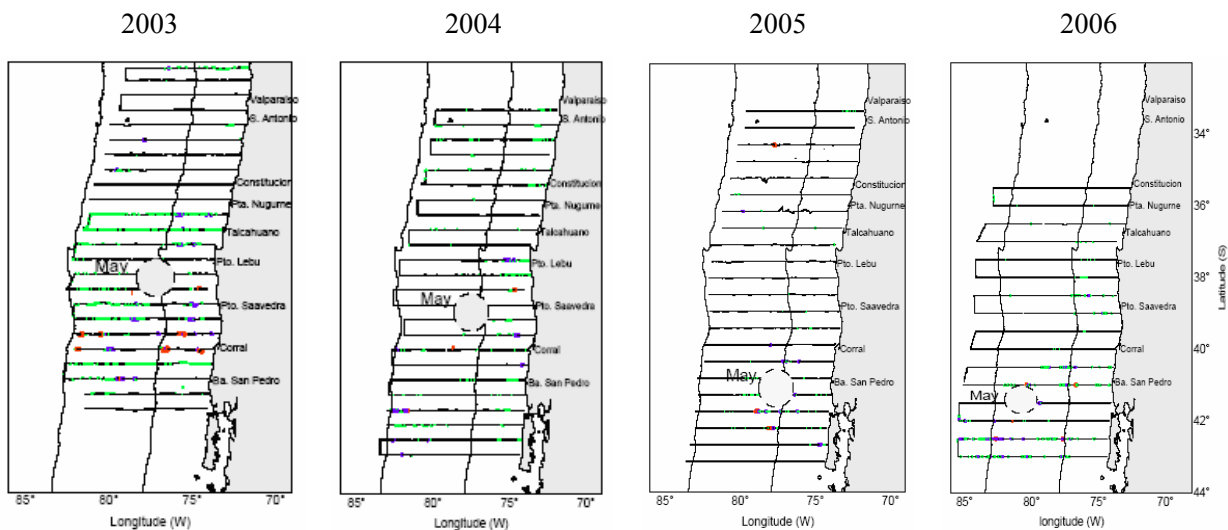


Figure 5.- Gravity center of jack mackerel spatial distribution from acoustic exploration.

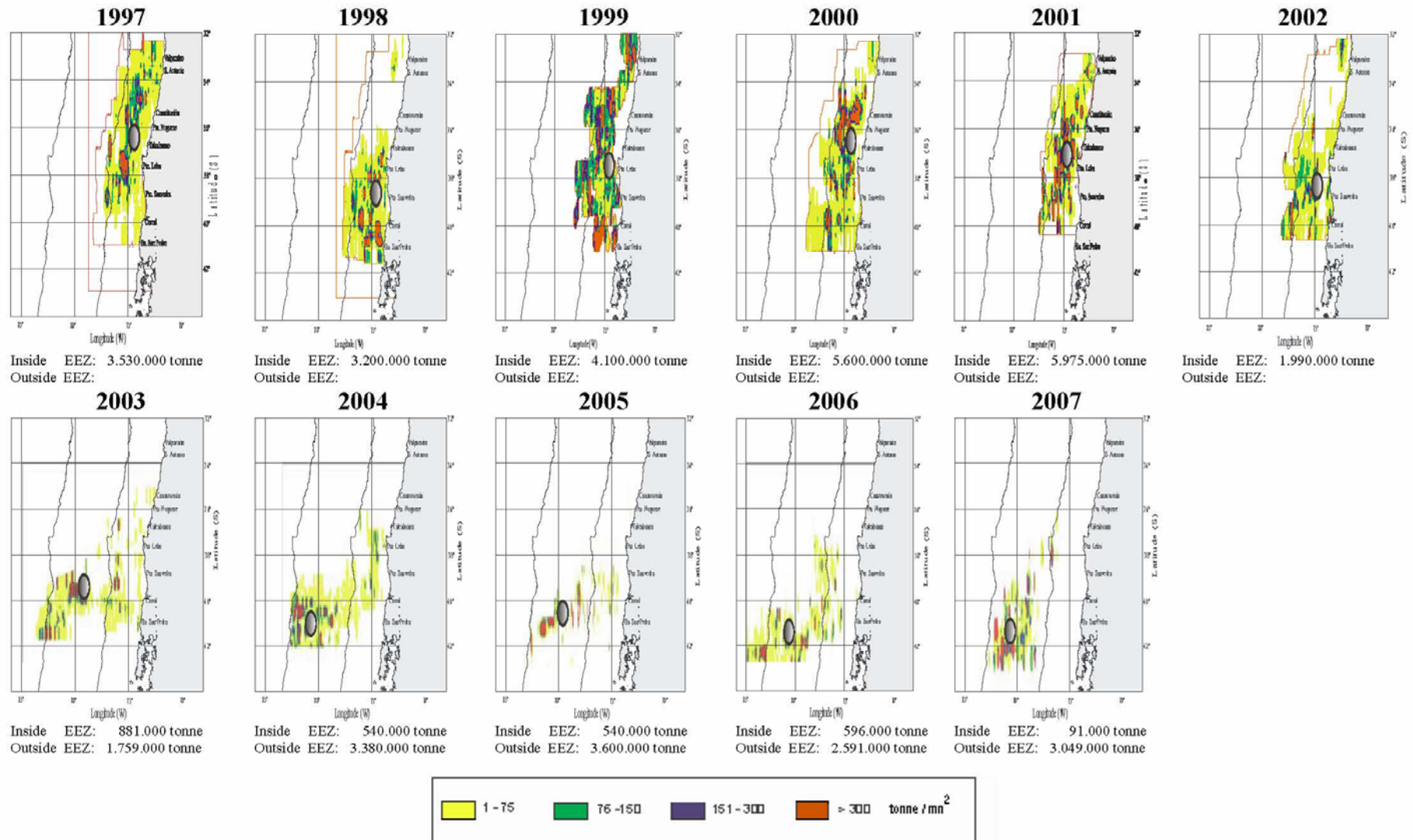


Figure 6.- Gravity center of jack mackerel spatial distribution from acoustic exploration.

Table 2.- Biomass and coefficient of variation (CV) inside-outside in the EEZ and total area (1997-2007)

Years	5-200 mn		200-400 mn		Total		
	Biomass (tonne)	CV	Biomass (tonne)	CV	Biomass (tonne)	CV	Area (mn ²)
1997	3. 530. 000	0,07			3. 530. 000	0,07	58.000
1998	3. 200. 000	0,08			3. 200. 000	0,08	47.540
1999	4. 100. 000	0,08			4. 100. 000	0,08	61.317
2000	5. 600. 000	0,12			5. 600. 000	0,12	65.196
2001	5. 970. 000	0,08			5. 970. 000	0,08	52.636
2002	1. 990. 000	0,09			1. 990. 000	0,09	53.496
2003	881. 000	0,27	1. 759. 000	0,10	2. 640. 000	0,11	53.129
2004	540. 000	0,16	3. 380. 000	0,14	3. 920. 000	0,12	66.636
2005	510. 000	0,26	3. 600. 000	0,09	4. 110. 000	0,09	57.226
2006	596. 000	0,29	2. 591. 000	0,22	3. 187. 000	0,18	52.886
2007	91. 000	0,27	3. 049. 000	0,13	3. 140. 000	0,13	35.748

On the other hand, the main acoustic density weighted for the sampling units with presence of jack mackerel shows a difference of distances off the coast for 1997 to 2007, an increase of the density in EEZ between 1997 to 2001, consistent with the steady increase in the biomass in this sector during this period (3,2 to 5.97 million tons). Outside the EEZ, 200 to 300 nm off the coast reveals a slight decreasing trend in the acoustic density between 2003 and 2007, while for the sector from 300 to 400 nm the values are stable (Figure 7). These variations of the abundance with regard to its location from the coast, confirms the strong change in the use of the jack mackerel space observed in the last years.

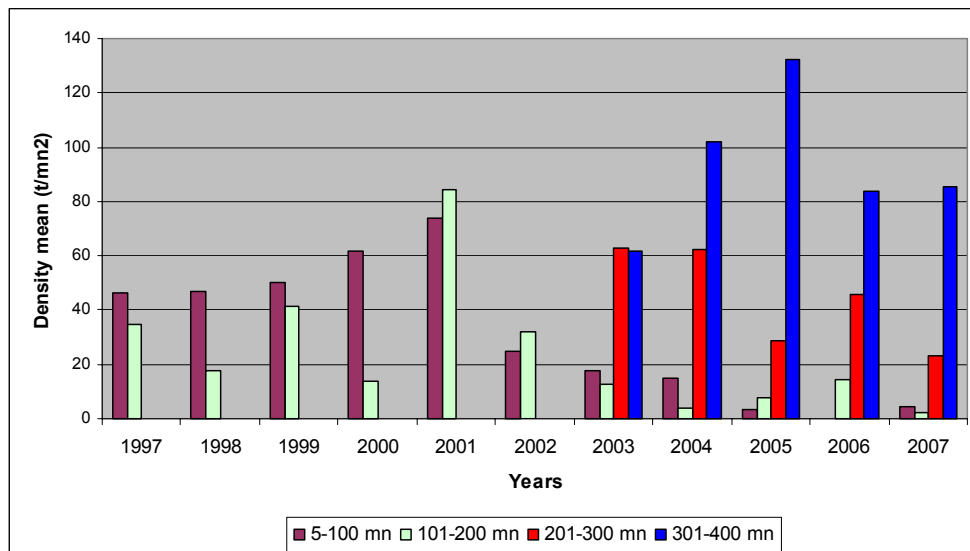


Figure 7.- Main acoustic density weighted by year and distance from the coast.

With this respect, the withdrawal of the resource off the coast, observed during May-June on the central zone of Chile, is also observed in the fishing zones movements towards offshore over the years. This situation was intensified during 2007 and became critical in the first 2008 semester, when the fishing zones were located in the border and outside the EEZ (L. Caballero pers comm.).

The results of acoustic explorations carried out from 2001 to 2007 to determine the spatial distribution of the spawning stock and the eggs density in high seas during the spawning period (spring) of the jack mackerel show a wide distribution of the resource in the different years (Figure 8). This would be sustained since the jack mackerel is a partial spawner, and its spawning strategy is aimed at covering wide areas to the north of the drift west current. Such strategy is different from the one observed in pelagic species such as sardine and anchovy, where the spawning is located in small or limited areas. For this spring period, a decreasing trend is observed in the relation between the high density area of eggs and the total explored area, from 46.3 % (2001) to 1.02 % (2007). This situation is also observed in the number of aggregations present in the area from 431 in 2001 to 53 in 2007, coinciding with the autumn decrease of aggregations present per nautical mile.

The larger amount of high density aggregations of jack mackerel registered in 2000 coincides with the highest biomass estimated in the 2001 autumn (5.97 million tons), presenting a gradual decrease of the number of high density aggregations later, reaching a minimum value in 2007. This decreasing trend is similar to the observed in the acoustic surveys carried out in the central coast of Chile during autumn.

During 1997 and 1998, an intense ENSO was recorded in the Southeastern Pacific, reaching to latitude 40°S. In this period, maximum anomalies (May-June 1997) of +2.5 °C were recorded in the zone where the fishery was located, together with an important presence of individuals of less than 26 cm (Cordova *et al.*, 1999-2001, NOAA Climate Bull, 1998). This represented about 80% of jack mackerel industrial landings during 1997 (Serra, 1998; Barria *et al.*, 1999), showing an important alteration in the marine environment during these years.

The high abundance of small jack mackerel in the acoustic survey and in the commercial fishery during 1997, suggests as an hypothesis the displacement of oceanic waters that include the transport of small fish (pre-recruitment) that habitually remain in the oceanic sector (A. Aranis, pers. comm., Arcos *et al.*, 2001). During the ENSO development, important changes happen in the spatial distribution of the different jack mackerel length groups, as

observed in the Soviet fleet catch outside the EEZ in front of Peru (1987–1988), with fork length of less than 29 cm (T. Diones, pers. comm.).

Then, if the conditions of the ENSO 1996-1997 are considered to have affected the distribution patterns of the juvenile fraction for three consecutive years (1996-1998), retaining the juvenile in the south, and to have affected strongly the annual classes from 1994 to 1997, configuring a new spatial pattern under which the population was, as well as the strong fishing exploitation that depressed the adult fraction, then, they indicate that the restoration of a "normal" pattern of the population will be a slow process, depending on the new annual classes re-discovering the old nursing zone (Arcos *et al.*, 2004). In this scene, it is possible to understand possible changes of adequacy in the spatial distribution of the jack mackerel.

The high variation of jack mackerel abundance inside and outside the EEZ, which currently supports the most important fisheries of the country, is associated to a strong change in its spatial distribution. It is necessary to ask if these spatial changes of the resource correspond to a decrease in the abundance or to a spatial change in the general distribution of the resource in the zone of study, which is relevant to know its impact in the commercial fishing and on the administration of the resource. With this respect, it is fundamental to have information outside the EEZ, which allows checking with indicators if this displacement of the areas of concentration of jack mackerel is limited to the evaluated area or extends along the high seas. This could confirm the hypothesis of a decrease in the general abundance of the resource.

4. Conclusions

Between 1997 and 2007, the jack mackerel has presented important interannual changes in abundance, with strong availability decrease in the ZEE, between 2001 and 2007 (5,97 millions to 91.000 tonne), as well as the displacement of high concentrations towards the south west of the area of study since 2003, making clear the withdrawal of the principal zones of concentration from the traditional areas.

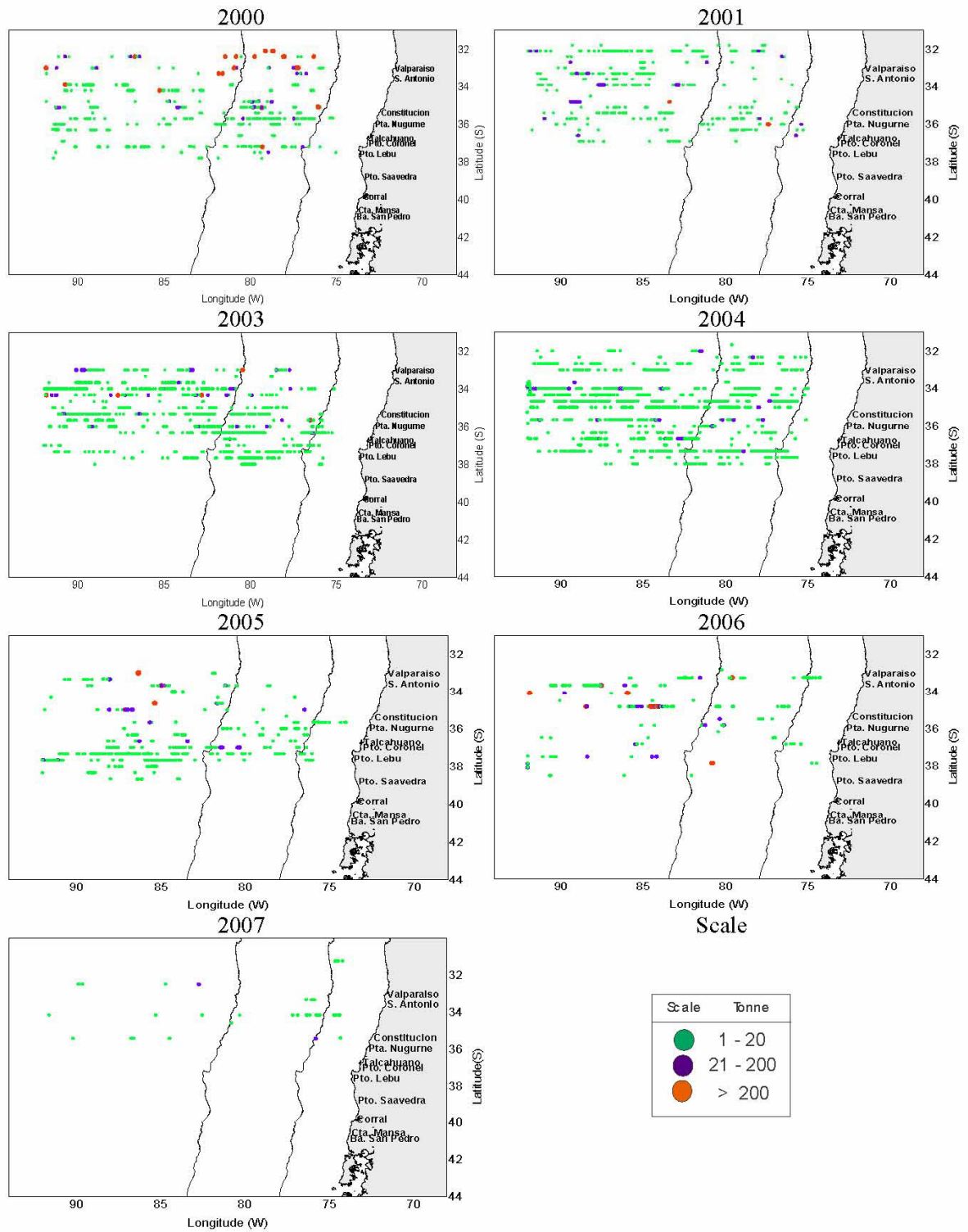


Figure 8.- Spring spatial distribution of jack mackerel from acoustic exploration

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