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ACOUSTIC BIOMASS OF JACK MACKEREL (*Trachurus murphyi, Nichols, 1920*) STRUCTURED BY SIZE AND AGE IN THE CENTRAL COAST OFF CHILE

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ABSTRACT

Annual acoustic surveys have been carried out in autumn in the central zone off Chile since 1991, in order to determine the distribution and biomass of jack mackerel. This document presents the results obtained in the 1997-2008 period, as well as the annual biomass of jack mackerel by size and age and its distribution. The study area limits and the sampling designs have been adapted to the distribution of jack mackerel each year, being located between Valparaiso and south Chiloe, and between 5 and 500 nm offshore. Between 1997 and 2002, the area studied was inside the Chilean Exclusive Economic Zone (EEZ), and the surveys were carried out only by R/V Abate Molina; the area would afterwards gradually extend west up to 500 nm and south.

The jack mackerel biomass estimated in the zone showed an increase in the 1997-2001 period going from 3.7 million tons in 1997 to 6.14 million tons in 2001; it showed a relatively steady period in 2004-2005, with about 4 million tons, and from 2005 on, the biomass showed a negative trend reaching the minimum of about 0.5 million tons in 2008. These results were associated with an important change in the distribution area.

Abundance by age and size does not show any difference inside and outside of the EEZ. In the 2003-2007 period, an increase in the modal size was observed jointly with a great importance of the oldest age classes; however, in 2008 the VII and VIII age classes were the most important.

INTRODUCTION

The Chilean jack mackerel presents two significant biological events: a spawning period in the southern spring, characterized by an oceanic distribution that has surpassed the 1000 nm offshore with dispersed aggregations, and a "*fattening*" period post spawning, in autumn and early winter, with bigger aggregations near the coast. This behavior is related to the seasonality in the captures and yields of the Chilean purse-seine fleet, as the biggest captures are registered during the first semester. In both, the spawning and fattening periods, acoustic surveys were carried out; in the spawning period acoustic surveys with several commercial vessels have been used aiming at obtaining an indicator of the distribution and the different types of aggregations related to spawning behavior; these studies began in the year 2000 and were interrupted in 2007.

The purpose of the autumn research was to determine the biomass and distribution of the jack mackerel available for the Chilean fleet. This piece of work was started in 1991 and has been used for two main purposes: learning about the migration patterns and estimating the biomass in the area of main concentration of the stock off Chile, which also corresponds to the main fishery zone (Figure 1). Acoustic biomass is the most important abundance index used for stock assessment purposes; its spatial and temporal variations have permitted the development of different hypotheses related to the stock status.

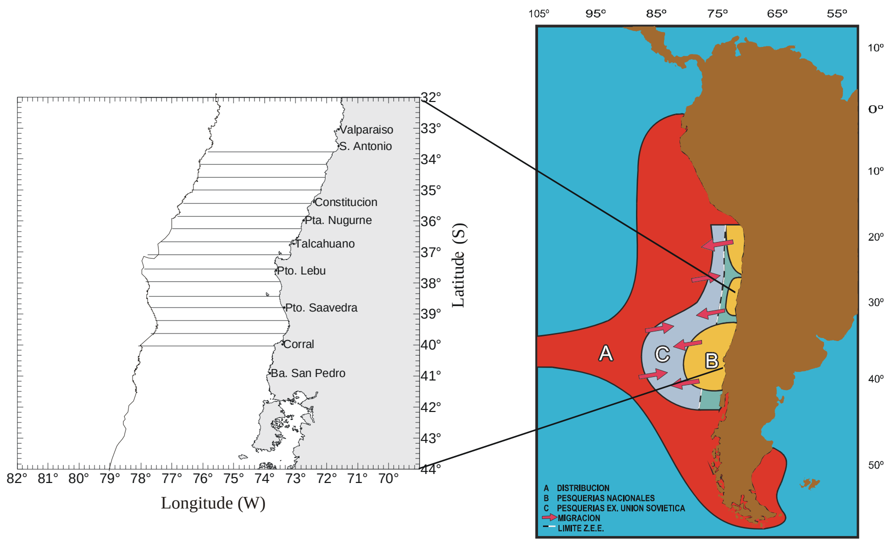


Figure 1.- Geographical distribution of *Trachurus murphyi* in the Southeastern Pacific and surveyed area.

In this work the acoustic biomass by size and age and its geographical distribution in autumn during the 1997-2008 period is shown, as well as the distribution of jack mackerel corresponding to the spawning period between 2001 and 2007.

MATERIALS AND METHODS

The area of study for the period 1997-2002 covers from south Valparaiso (33°20'S) to Corral (40°00'S), between the coast and the 200 nm offshore (Figure 2a); while from 2003 to 2008, the 200-to-500-nm sector was incorporated, extending the area also to the south to 43º S off Chiloe (Figure 2b and 2c).

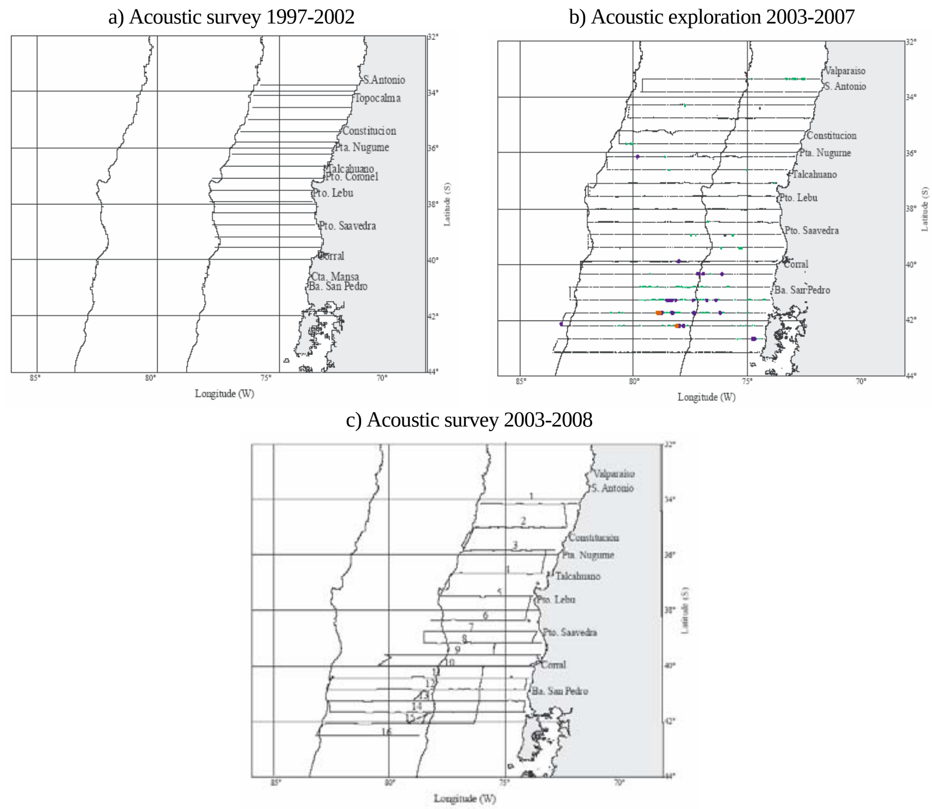


Figure 2.- Grid of track for acoustic explorations and survey

In view of 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, a fast acoustic exploration using echosounders and sonars is carried out with several commercial fishing vessels that sail simultaneously to determine the areas of main concentration of the resource, and to adjust the sampling design of the second stage. In the second stage, an acoustic survey is conducted with standard and calibrated scientific echosounder, using two commercial fishing vessels equipped with echosounder (SIMRAD EK-60), split beam transducer of 38 Khz, sonars and midwater trawls, and the R/V Abate Molina, equipped with echo sounder Simrad EK-500, and also with midwater trawl**.**

Before each cruise, the echo sounder Simrad EK-500 of the R/V "Abate Molina" and Simrad EK-60 from the purse-seiners were calibrated with standard methods (Foote et al. 1987; Simrad,1991, 2003)

A systematic sampling design with equidistant transects perpendicular to the coast was applied for assessing the biomass and distribution of jack mackerel (Barbieri *et al,* 1996; MacLennan & Simmonds, 1992), with a 25-nm separation (Figure 2a and 2c), increasing the separation in the north (EEZ) because of the scarce presence of jack mackerel.

In the acoustic exploration carried out with commercial fishing vessels in spring previous to the biomass survey, the aggregations registered with echosounder and sonar were classified in six density categories: shoal, high density, medium density, low density layers, dispersed, and low density shoal (Figure 3). Also a relative density scale, according to skipper appreciation, was used: low (<20 tons); medium (20-200 tons); and high (> 200 tons).

Two methods were used for species identification from acoustic echograms. The first method applies the methodology developed by IFOP's Unit of Acoustics (Guzmán *et al*, 1983), based on the volume backscattering coefficient (Sv). The second method consists of the examination of echograms and trawls for species identification (Simmonds and MacLennan 2005). This information is complemented with the catch of the commercial fleet, when they coincide in space and time with the cruise.

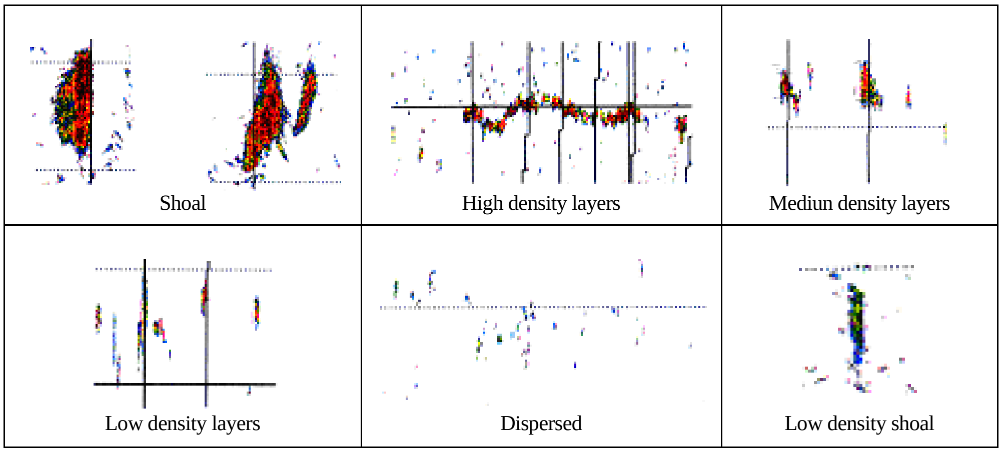


Figure 3.- Types of jack mackerel aggregations.

The local densities of jack mackerel by ESDU are mapped in contour charts with four density category levels (Software Surfer 8.0), where the curves join equal density points, allowing emphasizing the areas of major concentration of the resource (MacLennan and Simmonds, 1992).

The jack mackerel biomass is estimated according to the following formulation:

$$\hat{A}_t = \sum \hat{A}_k \quad ; \quad \hat{B}_t = \sum \hat{B}_k$$

And

$$\hat{A}_k = a\,\hat{C}_{nk}\,\hat{S}_{a\,k}\,(4\pi\,10^{0.1\,\hat{TS}_k})^{-1}\,; \qquad \hat{S}_{a\,k} = \hat{S}_a\,\hat{P}_k\,; \qquad \hat{B}_k = \hat{A}_k\,\hat{w}_k$$

Where a is the area of distribution of jack mackerel (nm^2); $\hat{S}_A$ is the acoustic mean density in the distribution area; $\overline{w}_k$ is the mean weight of the jack mackerel at size k ; $\hat{P}_k$ is the size frequency (k) of jack mackerel; and $\overline{TS}_k$ is the target strength of fish at mean length (k) (dB).

Target strength (TS) was calculated from the model TS = 20.11 Log (L) – 68.67 (Córdova et al., 1998).

The variance of the biomass was estimated with a geostatistical approach (Petitgas and Lafont, 1997). The precision level for these estimates was expressed by the coefficient of variation (CV) defined by:

$$CV = (\hat{B})(\sqrt{V(\hat{B})})^{-1}$$

RESULTS AND DISCUSSION.

The acoustic surveys carried out between 1997 and 2008 showed that the number of aggregations (number of schools/nautical miles) decreased from 8 to 2 (Table 1).

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

Years	Number of aggregations per nautical mile (%)							
	1	2	3	4	5	6	7	8
1997	52.3	25.5	11.6	5.5	2.6	2.0	0.3	0.2
1998	63.2	22.1	9.6	2.2	2.2	0.7		
1999	69.5	20.9	6.4	2.5	0.7			
2000	70.9	17.4	10.0	1.3	0.4			
2001	71.4	25.9	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						
2008	94.5	5.5						

With this respect, changes in the use of the space by the jack mackerel are also observed since 2003. The spatial distribution of the resource (Figure 4) arising from the acoustic explorations conducted until 2006 shows changes in the centers of gravity towards the south of the area studied (Barbieri *et al.*, 2003-2005 and Bahamonde *et al.*, 2006). This is confirmed by the centers of gravity estimated in the acoustic surveys carried out later in the zone, showing stability in the distribution of the aggregations of jack mackerel at least for less than a month scale time (Figure 5). It is important to highlight this aspect, because this straddling pelagic species presents important mesoscale movements.

The presence of the resource outside the EEZ registered by the acoustic exploration previous to the acoustic survey is also observed in the magnitude of the abundance estimated inside and outside the EEZ, showing in the first 200 nm a strong decrease of the biomass estimates, from 6.14 million tons in 2001 to 1,457 tons in 2008; while outside the EEZ, the levels increased from 1.831 million tons in 2003 to 3.155 million tons in 2007, but the total biomass decreased strongly in 2008 to around 0.5 million tons (Table 2). This negative trend is maintained in 2009, because preliminary results from the survey conducted in 2009 gave a lower estimate.

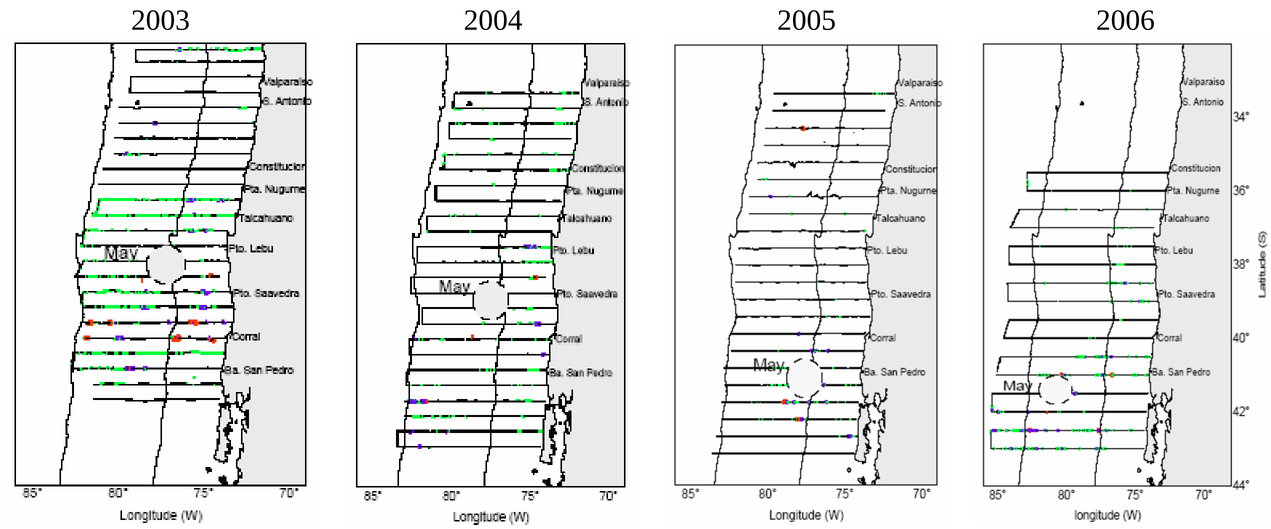


Figure 4.-Centers of Gravity of spatial distribution of jack mackerel arising from acoustic exploration.

Table 2.- Biomass and coefficient of variation (CV) inside-outside the Chilean EEZ and total area (1997-2008). The western limit in 2006 was 500 nm and 480 nm in 2008.

Years	5-200 nm		200-400+ nm		Total		
	Biomass (tons)	CV	Biomass (tons)	CV	Biomass (tons)	CV	Area (mn^2)
1997	3,753,516	0.044			3,753,516	0.044	58,000
1998	3,255,838	0,039			3,255,838	0.039	47,540
1999	4,354,999	0.031			4,354,999	0.031	61,317
2000	5,889,227	0.049			5,889,227	0.049	65,196
2001	6,146,418	0.034			6,146,418	0.034	52,636
2002	2,027,384	0.040			2,027,384	0.040	53,496
2003	914,653	0.090	1,831,599	0.067	2,746,252	0.051	53,129
2004	529,790	0.068	3,495,064	0.057	4,024,854	0.051	66,636
2005	583,259	0.106	3,503,062	0.035	4,086,322	0.034	57,226
2006	612,457	0.125	2,827,428	0.075	3,439,885	0.060	52,886
2007	87,753	0.121	3,155,924	0.057	3,243,676	0.055	35,748
2008	1,457	0.100	487,507	0.130	488,965	0.120	8,621

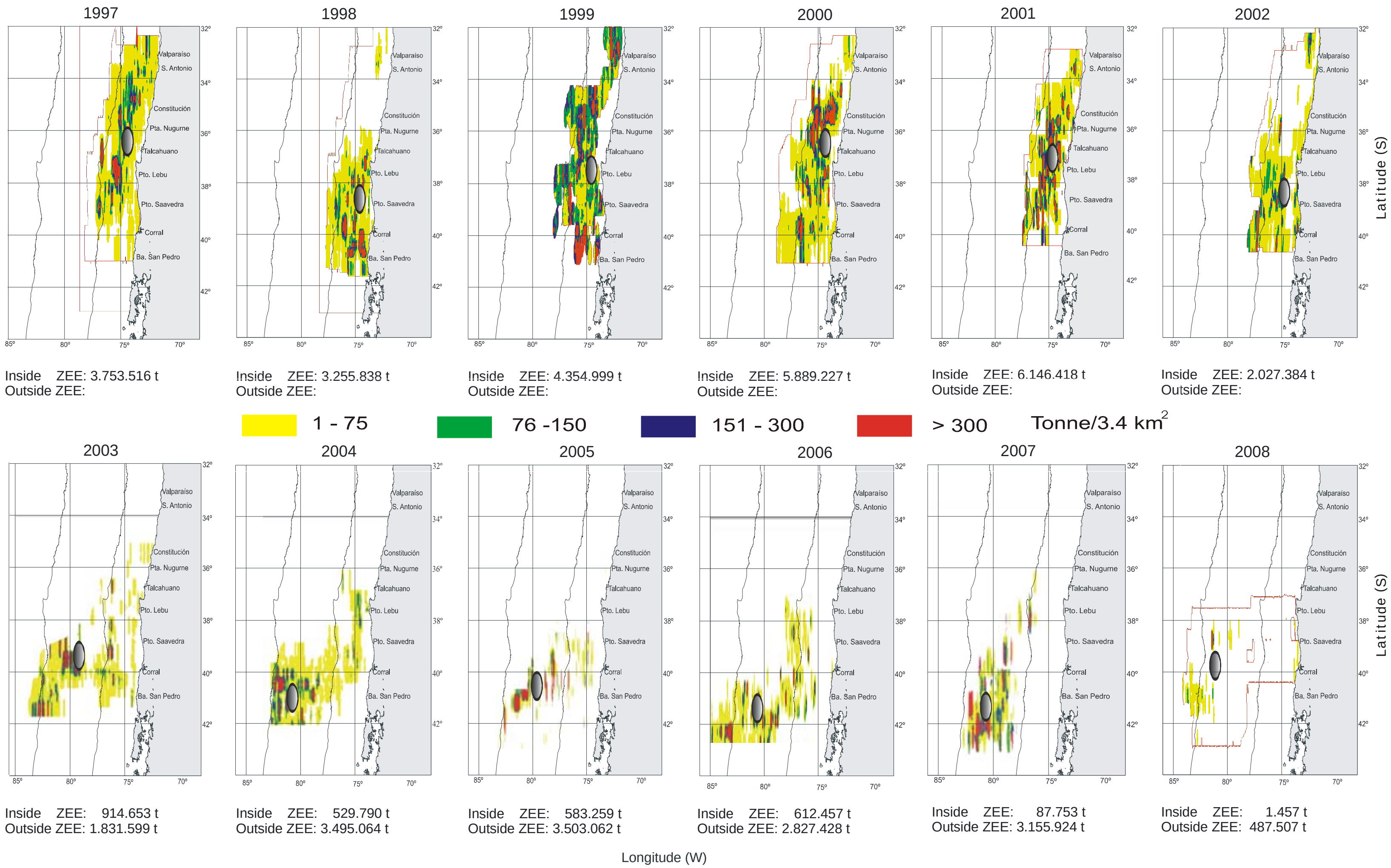
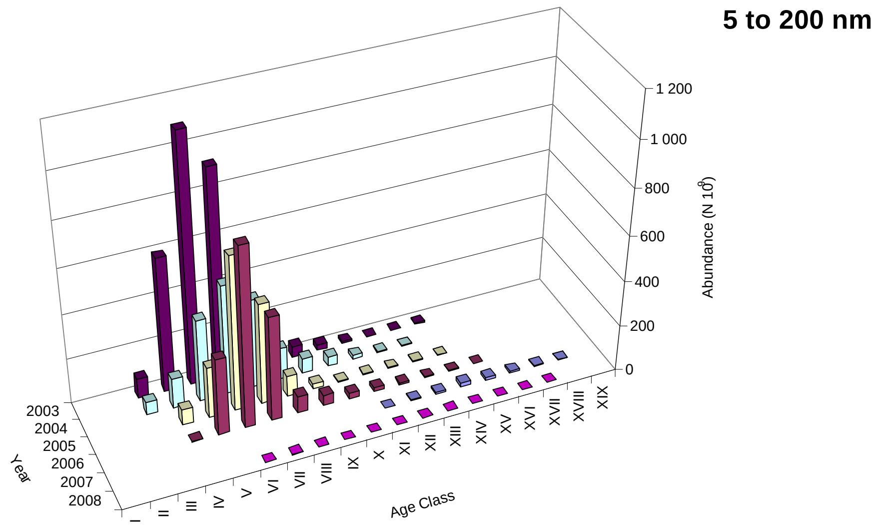


Figure 5.- Spatial distribution of jack mackerel from acoustic biomass assessment between 1997 and 2008. Centers of Gravity are indicated

Since the year 2000, the acoustic biomass of jack mackerel was referenced to age. Figure 6 shows the age structure of the stock for the zone 5-200 nm and 200(+)-400 nm, and Figure 7 shows the abundance by age inside and outside the EEZ. It is important to highlight that there are no differences in the size and age structure of the jack mackerel stock from both sectors. Figure 8 shows that in the period 2000-2003 the modal size of jack mackerel was 26 cm for the whole zone (5-400 nm), represented by age IV and V. From 2003 to 2006, an increase in the modal size was observed jointly with a great importance of the oldest age classes, (age classes V and VII were the most important). The trend became more evident in 2007 as age XIV and XV were the most representative. Nevertheless, in 2008 age classes VII and VIII were the most important.



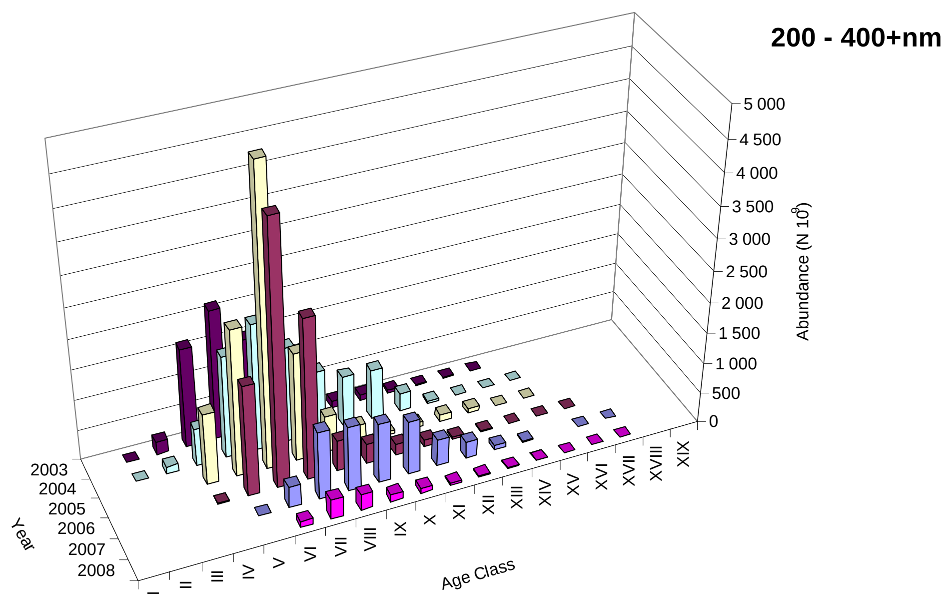


Figure 6.- Acoustic abundance (N°) of jack mackerel by age in the zone 5 to 200 and 200 (+) to 400 nm; the western limit in 2006 was 500 nm, and 480 nm in 2008.

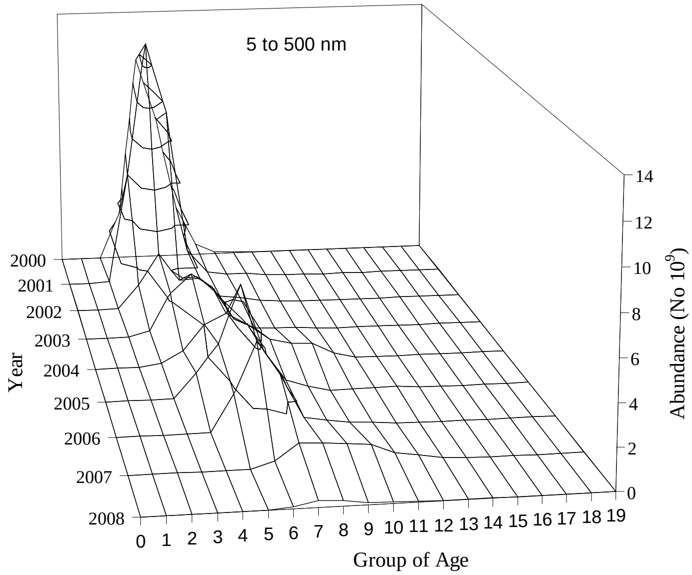


Figure 7.- Acoustic abundance of jack mackerel structured by age in the zone 5 to 400 (+) nm in the period 2000-2008. The western limit in 2006 was 500 nm, and 480 nm in 2008.

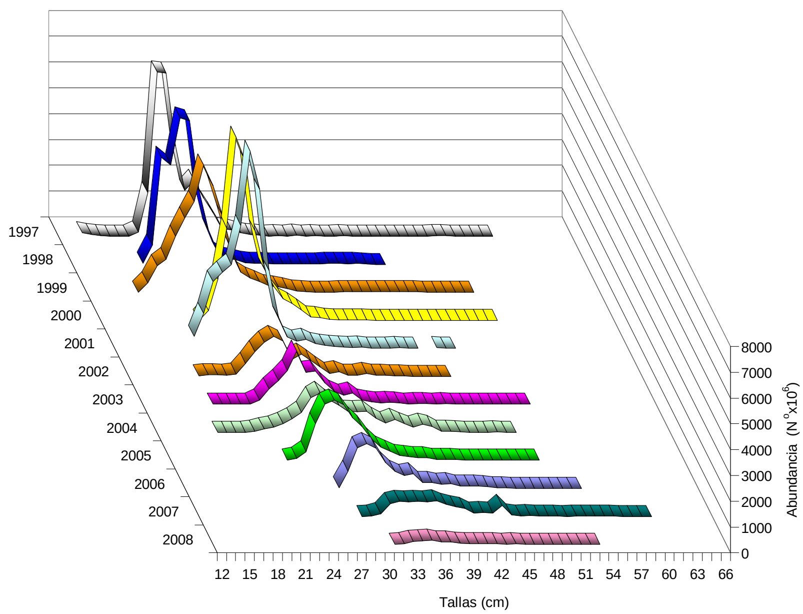


Figure 8.- Abundance (N^o) of jack mackerel structured by size in the period 1997-2008 between 5- 400 + nm offshore.

On the other side, the results of acoustics explorations with commercial vessels conducted in spring from 2001 to 2007, to determine the spatial distribution of the spawning stock of jack mackerel and the eggs density, show a wide distribution in the different years (Figure 9) and a negative trend in the number of aggregations in the area from 431 in 2001 to 53 in 2007, which coincides with the autumn decrease of aggregations present per nautical mile. The largest amount of high-density aggregations registered in the year 2000 coincides with the highest biomass of 6.14 million tons estimated in the 2001 autumn, showing a gradual decrease of the number of high-density aggregations later, reaching the minimum value in 2007.

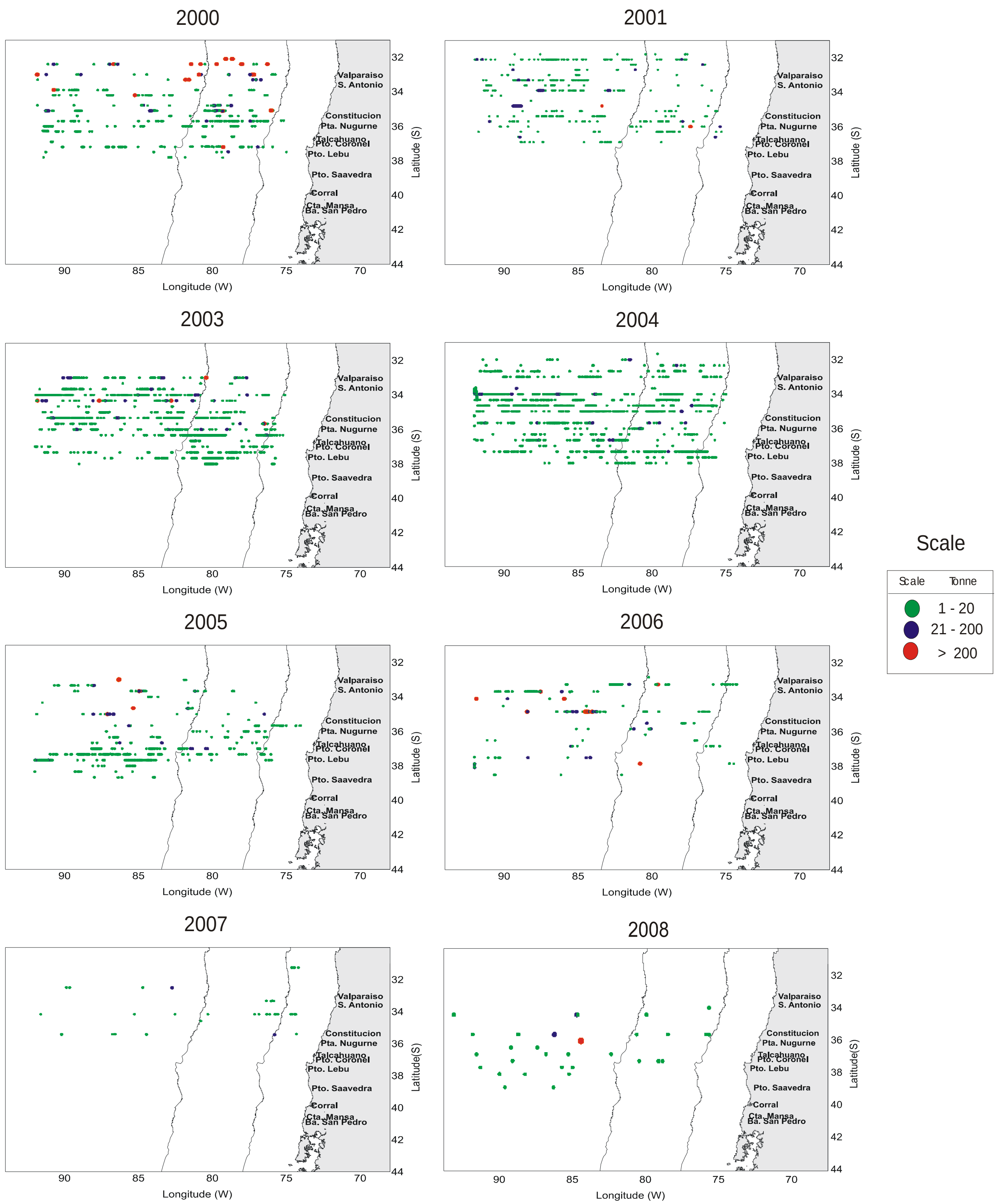


Figure 9.- Spatial distribution of jack mackerel from acoustic exploration in spring.

CONCLUSIONS

- The biomass of jack mackerel estimated by acoustic surveys in the entire zone reached a maximum in 2001 with 6.14 million tons and a relative stabilization in the period 2004-2005 with around 4 million tons. From 2005 the biomass had a negative trend until reaching the minimum in 2008, around 0.5 million tons.
- Between 1997 and 2000 the jack mackerel was mostly inside the Chilean EEZ; from 2001 the resource in this zone declined strongly until a minimum of 1.5 thousand tons in 2008.
- There are no differences in the size and age structure of the jack mackerel stock inside and outside the EEZ. An increase in the modal size and in the age class is verified from the periods 2000-2003 to 2007. Nevertheless in 2008 a reduction in the modal age classes is observed.
- Acoustic biomass estimates must be considered as indexes of abundance and not as absolute values.

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