ICES Journal of Marine Science, 53: 429–433. 1996

Analysis of Spanish acoustic surveys for sardine, 1991–1993: abundance estimates and inter-annual variability

C. Porteiro, P. Carrera, and J. Miquel

Porteiro, C., Carrera, P., and Miquel, J. 1996. Analysis of Spanish acoustic surveys for sardine, 1991–1993: abundance estimates and inter-annual variability. – ICES Journal of Marine Science, 53: 429–433.

Systematic acoustic surveys to estimate the Spanish fraction of the Atlantic sardine stock were begun in 1983. Since 1991, with the use of the new SIMRAD EK500 echo-sounder–echo-integrator, the area covered has been extended to the 1000 m depth contour to observe the complete distribution of the main pelagic species. The last three surveys, from spring 1991 to spring 1993, had a range of 20–1000 m depth. They were first analysed using traditional methodology, which does not give any estimation of the variance. The data were therefore analysed using geostatistical techniques and the resulting estimates of relative abundance were compared. Sardine showed high variability between years and zones both in distribution and density, expressed as number of fish per square nautical mile. The two methods of analysis gave different biomass estimates by zone, especially in 1993. Variograms computed over areas of fish presence did not show, in general, a clear spatial structure and sills were reached at 3 nmi of range. The precision of these variograms was low, ranging from 23–40%, expressed as relative standard error. In order to improve precision it is necessary to increase sampling intensity and change the survey grid. For sardine, a systematic parallel survey design with a random start and 6 nmi between transects would be more appropriate.

Key words: acoustic survey, geostatistics, Iberian Peninsula, *Sardina pilchardus*, spatial distribution.

C. Porteiro: Instituto Español de Oceanografía, Centro Oceanográfico de Vigo, Apartado 1552, 36280 Vigo, Spain. P. Carrera: Instituto Español de Oceanografía, Centro Oceanográfico de A Coruña, Apartado 130, 15080 A Coruña, Spain. J. Miquel: Instituto Español de Oceanografía, Centro Oceanográfico de Baleares, Apartado 291, 07080 Palma de Mallorca, Spain. Correspondence to Carrera [tel: +34 8120 5362, fax: +34 8122 9077].

Introduction

Sardine (*Sardina pilchardus* Walbaum) is the target of an important fishery along the Atlantic coast of the Iberian Peninsula. It is jointly exploited, mainly by Portuguese and Spanish purse-seiners, in ICES Divisions VIIIc and IXa. Since 1976, different methods have been applied to assess this stock, such as tuning of VPA, acoustics, and the daily egg and production model (DEPM) (Pestana, 1989; Garcia *et al.*, 1991). Since 1982, the Instituto Español de Oceanografía (IEO) has undertaken systematic acoustic surveys, their main objective being to obtain annual estimates of sardine abundance in the Spanish area of the Atlantic coastal waters of the Iberian Peninsula.

The echo-integrator method for estimating fish abundance uses continuous sampling, which allows total stock biomass to be estimated. As well as mean values, a measure of the associated variance is necessary in order to know confidence intervals and precision. Methods of calculating associated variance are summarized in Simmonds *et al.* (1992).

This paper analyses the results of the surveys carried out in spring 1991 to 1993. A first analysis used the traditional methodology proposed in Pastor *et al.* (1986), which does not give any estimation of the variance. The data were therefore also analysed using geostatistical techniques and the resulting estimates of relative abundance compared.

Materials and methods

The surveys, carried out on board RV ‘‘Cornide de Saavedra’’ during March–April, were conducted day and night at a ship speed of 10 knots. A split-beam 38 kHz SIMRAD EK500 echo-sounder–echo-integrator was used. Integrated values, expressed as backscattering

1054–3139/96/020429+05 $18.00/0

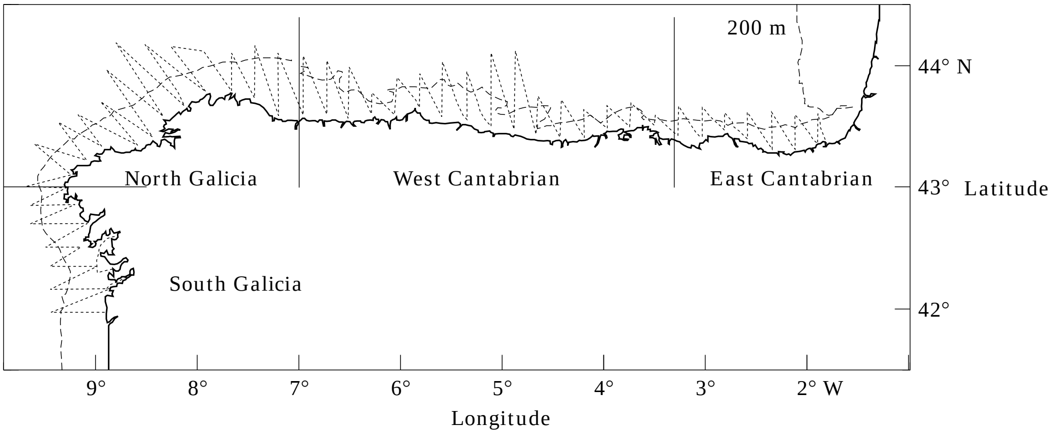

Figure 1. Survey design followed during cruises and main zones.

units or S_A values (m^2 nmi^{-2}) (Bodholt, 1990), were directly collected every nautical mile and stored in a PC, which controlled the main features of the sounder. Geographical position was also taken by GPS.

Before each survey, the echo-sounder was calibrated as described by Foote *et al.* (1987) using a copper sphere as a standard target with a TS of −33.6 dB.

The survey track was carried out over the probable distribution area of the main pelagic species (i.e. sardine and blue whiting). Each year the track comprised a zigzag design, with 10–12 nmi between turning points, a 20 m depth lower limit (modified when bottom topography, islands, or shallows required it), and 1000 m depth external limit, which was also adapted according to the presence of blue whiting.

Based on the information obtained at pelagic fishing stations, total S_A values for each nmi were allocated into different species (sardine, blue whiting, and others). This kind of allocation did not present great problems and sardine records could be distinguished and allocated even at night. S_A values for sardine corresponded to 1 nmi of track. The geographical positions expressed in coordinates of latitude and longitude multiplied by the cosine of the mean latitude were used to calculate distances, surfaces, and arithmetic mean values, using two different methods:

(a) Fixed strata: The surveyed area was divided into 21 geographic sectors with a width of 20 nmi and each sector was also divided into depth strata (20–50 m, 50–100 m, and 100–200 m) (Pastor *et al.*, 1986). Means were calculated using all the data within these areas, with null values included. For the results, the area was split into four zones along the coast as follows: South Galicia, from the Spanish–Portuguese border to 43°N (Cape Fisterra); North Galicia, from 43°N to 7°W; West Cantabrian, from 7°W to 3°20′W; and East Cantabrian from 3°20′W to the Spanish–French border (Fig. 1). These four zones correspond to the sardine age-distribution pattern found in these waters, with juveniles and young fish in South Galicia and an age gradient running from there to the East Cantabrian where the oldest sardines can be found (Porteiro *et al.*, 1986).

(b) Distribution area: The area of sardine presence was determined for each survey. The external boundaries of these areas were defined by the presence of a succession of zero values along transects and/or the lack of positive values in two consecutive transects. In each survey, this definition gave isolated areas along the coast, which correspond, more or less, with the four main zones described above. Inside them, holes in density can be also observed. Spatial structures, surfaces and estimations of the variance were calculated by means of geostatistical techniques (Petitgas, 1993) using the EVA package (Petitgas and Prampart, 1993).

Abundance estimates were calculated according to the methodology proposed in ICES (1986) using the TS–length relationship for herring (Dengbol *et al.*, 1985), which has been adopted for sardine (Anon., 1986): $TS = 20 * \log(L) - 72.6$ (dB). For purposes of comparison, results were grouped using the four zones described above.

Results

Each of the four zones showed a distinct distribution structure, which is more or less constant every year. Within each zone, data showed skewed distributions with a few high values representing 85–95% of the variances and 45–66% of the arithmetic means. The main features of the data gave 2D variograms, calculated along and across transects, with no clear spatial structure. By transforming raw data to a logarithmic scale, clear spatial structures appeared for 1993 in the East Cantabrian and in the eastern part of the West Cantabrian; other structures were close to a simple random component (nugget effect) and sills seemed to

Table 1. Mean S_A value for sardine, fitted variogram, variance estimate and surface (nmi^2) for each area of sardine presence, zone, and year (na = not available).

Zone	Year	Area	Mean (S_A)	Variogram nugget + spherical (sill, range)	Variance estimate	Surface (nmi^2)
S. Galicia	1991	Whole	99.36	na	na	255.2
	1992	Whole	427.33	na	na	113.6
	1993	Whole	326.36	253 000 + (317 000, 3)	7 302.28	231.1
N. Galicia	1991	Whole	70.11	na	na	234.80
	1992	Whole	344.77	na	na	100.17
	1993	Whole	182.85	20 000 + (23 000, 3)	1 739.56	221.22
W. Cantabrian	1991	West	534	500 000 + (490 000, 3)	36 579.31	545.7
		East	923.64	2 100 000 + (1 500 000, 3)	131 810.4	441.2
	1992	West	128.41	18 750	852.57	188.7
		East	696.76	1 100 000	64 705	168.5
	1993	West	540.82	1 612 500 + (2 687 500, 4)	82 749.39	615.0
		East	138.71	245 000 + (105 000, 6)	17 346.54	1079.8
E. Cantabrian	1991	Whole	510	130 000 + (240 000, 3)	36 678.1	135.8
	1992	Whole	127.68	47 000	1678.67	169.2
	1993	Whole	203.96	120 000 + (280 000, 6)	4992.2	593.1

be reached at 3 nmi. Mean S_A values, experimental variograms, variance estimates (when available) and surfaces by geographic zone are shown in Table 1.

In South Galicia, sardine were present only in shallower waters close to the coast. In 1991 and 1992, sardine were found mainly in small, isolated patches, all of them close to the coast, which did not allow the creation of variograms. In 1993, experimental variograms could be fitted to a spherical model with a range of 3 nmi.

North Galicia showed the same pattern each year, with small, separated patches which again did not allow the creation of variograms, and only in 1993 was a variogram computed using an area of 100 nmi^2. Patches were distributed around 40–150 m of bottom depth.

In the West Cantabrian, sardine showed a widespread distribution, as far as 200 m depth, with two main areas separated at 4°30′W where the Llanes canyon is found. The smallest distribution area was found in 1992 and the largest in 1993. In 1991 and 1993, there were concentrations close to the coast and offshore with no connection between them. Variograms in 1992 did not show any spatial structure and, therefore, they were only used to determine the nugget effect.

The East Cantabrian had more or less the same structure as the West Cantabrian. In 1991, positive samples were scarce and close to the coast, continuous with samples for the West Cantabrian. In 1992, the distribution was isolated from that of the West Cantabrian, with no spatial structure. The distribution area was largest in 1993 but, as in the West Cantabrian, it had empty patches within.

Relative standard errors of the estimations by areas, calculated using theoretical variograms fitted to each spatial structure, ranged from 23–40%, except in the West Cantabrian in 1993 where the precision was lower.

Biomass estimates for each zone and year for both evaluation methods are given in Table 2. There was no consistency between methods for each zone and year, and differences were higher than 10%, except for South

Table 2. Biomass estimates (tonnes) for each method and percentage of difference by zone and year. Method I = fixed strata; method II = distribution area.

Year	Method	S. Galicia	N. Galicia	W. Cantabrian	E. Cantabrian	Total
1991	I	3111	10 683	75 711	16 429	105 934
	II	9018	3889	93 386	12 306	117 893
	Dif (%)	34.50	274.68	81.07	133.51	89.96
1992	I	8409	13 559	11 063	11 987	54 016
	II	10 410	9394	20 150	5358	45 311
	Dif (%)	80.78	144.34	54.90	223.73	99.35
1993	I	18 551	10 872	65 701	31 233	126 356
	II	17 953	9098	124 357	31 672	183 081
	Dif (%)	103.33	119.50	52.83	98.61	69.02

Galicia and the East Cantabrian in 1993. Despite this, differences were less than 11% for 1991 and 1992 for total estimates.

Discussion

The most important characteristic of the sardine distribution is the high variability between years. There seems to be a relationship between area and temperature, as suggested by Porteiro *et al.* (1993). In 1992, the temperature at 50 m depth was the coldest in this series and the area was the smallest; 1993 was the warmest year and the biggest area was found. This pattern agrees with those found for similar species, e.g. Japanese sardine (*Sardinops melanostictus*, Aoki and Inagaki, 1993). Also changes in stock size may produce a reduction in its lifespan and also in migration range (Lluch-Belda *et al.*, 1989). Both phenomena could explain the changes in distribution area detected in this paper.

Differences in total biomass estimates with the two methods were negligible for 1991 and 1992, but important for 1993, which was 30% higher when the distribution area method was used. Differences among areas were higher, especially in 1991 and 1992 and in West Cantabrian in 1993. These differences can be explained by the different mean values and areas used in the two methods.

As sardine are distributed mainly close to the coast, in 1992 in particular, variograms showed cyclical structures related to the scarcity of paired values of between 6 and 10 nmi separation, and this might explain the lack of spatial structure. Besides the lack of independent transects, zigzag survey designs provide higher local sampling intensity per unit area at the turns compared with other portions of the track (Simmonds *et al.*, 1992). In such conditions, areas with high density close to the turns and/or raw data with skewed histograms with high variances, as in the West Cantabrian in 1993, could give unrealistic variograms. This could explain the lack of clear spatial structures found for the different zones and their low precision.

In order to improve precision, it is necessary to increase sampling intensity and to change the survey grid to avoid problems when variograms are calculated. For sardine, a systematic parallel survey design with a random start and 6 nmi between transects would be more appropriate. This survey design would allow 1D and 2D variograms to be computed. It would also improve precision and help avoid the problems related to zigzag design. Because of the high variability in sardine distribution between years, the stratified random transect design, as proposed by Jolly and Hampton (1990) to give an unbiased variance estimate, would not be useful: the great variation in density would not allow pre-stratification nor would it be possible to allocate transects with the sampling intensity chosen according to the expected density.

Acknowledgements

Xabier Pastor and Carlos Afonso Dias were pioneers in Spain and Portugal in the use of acoustic methods for the evaluation of stocks. Their methods and their teaching made it possible for us to improve on those first experiences. We would therefore like to thank them for their work. We would also like to thank the staff who took part in the cruises and the crew of RV ''Cornide de Saavedra''. We are also indebted to the anonymous referees who helped improve the paper.

References

Aoki, I. and Inagaki, T. 1993. Acoustics surveys of abundance and distribution of the Japanese sardine *Sardinops melanostictus* in the spawning grounds off Southern Kyushu, Japan. Nippon Suisan Gakaishi, 59: 1727–1735.

Bodholt, H. 1990. Fish density derived from echo-integration and *in situ* target strength measurements. ICES CM 1990/B: 11, 15 pp.

Dengbol, P., Lassen, H., and Stæhr. 1985. *In situ* determination of target strength of herring and sprat at 38 and 120 kHz. Dana, 5: 45–54.

Foote, K. G., Knudsen, H. P., Vestnes, G., MacLennan, D. N., and Simmonds, E. J. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. Cooperative Research Report, International Council for the Exploration of the Sea, 144.

García, A., Pérez, N., Porteiro, C., and Carrera, P. 1991. Estimates of the sardine spawning stock biomass of the Galician and Cantabrian coast. ICES CM 1991/H: 35, 20 pp.

ICES, 1986. Report of the Planning Group for Acoustic Surveys in ICES Sub-Areas VIIIc and IXa. Lisbon, 1–4 April 1986. ICES CM 1986/H: 27, 7 pp.

Jolly, G. M. and Hampton, I. 1990. A stratified random transect design for acoustic surveys of fish stocks. Canadian Journal of Fisheries and Aquatic Sciences, 47: 1282–1291.

Lluch-Belda, D., Crawford, R. J. M., Kawasaki, T., MacCall, A. D., Parrish, R. H., Schwartzlose, R. A., and Smith, P. E. 1989. World-wide fluctuations of sardine and anchovy stocks: the regime problem. South African Journal of Marine Science, 8: 195–205.

Pastor, X., Poreiro, C., Alvarez, F., and Miquel, J. 1986. Acoustic abundance estimation of sardine (*Sardina pilchardus*, Walbaum) off Cantabric and Galician waters, March 1986. ICES CM 1986/H: 20, 8 pp.

Pestana, G. 1989. Manancial Ibero-Atlántico de sardinha (*Sardina pilchardus*, Walb) sua avaliaçao e medidas de gestao. Unpubl. thesis (mimeo, in Portuguese).

Petitgas, P. 1993. Geostatistics for fish stock assessments: a review and an acoustic application. ICES Journal of Marine Science, 50: 285–298.

Petitgas, P. and Prampart, A. 1993. EVA (Estimation Variance). A geostatistical software on IBM-PC for structure characterisation and variance computation. ICES CM 1993/D: 65, 32 pp.

Porteiro, C., Alvarez, F., and Pereiro, J. A. 1986. Sardine (*Sardina pilchardus*, Walb) stock differential distribution by age class in ICES Divisions VIIIc and IXa. ICES CM 1986/H: 28, 19 pp.

Porteiro, C., Miquel, J., Carrera, P., Meixide, M., and Cabanas, J. M. 1993. Abundance estimation and distribution of sardine in northern Spain (North of IXa and VIIIc Divisions). ICES CM 1993/H: 28, 19 pp.

Simmonds, E. J., Williamson, N. J., Gerlotto, F., and Aglen, A. 1992. Acoustic design and analysis procedure: a comprehensive review of current practice. ICES Cooperative Research Report No. 185.