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The characterization of sardine (*Sardina pilchardus* Walbaum) schools off the Spanish-Atlantic coast

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This paper describes the main characteristics of sardine schools detected in the Spanish-Atlantic surveys carried out from 1992 to 1997 (except 1994). A series of parameters were obtained for each school (morphological, positional and energetic) as well as environmental factors (temperature and salinity). The relationships between the school parameters were analyzed by a PCA and then the school parameters *per se* were described using both univariate and multivariate analyses (Box-plots, ANOVAs, MANOVA, and discriminant analysis). The results show that significant differences exist between years and geographic areas in that the Rías Baixas schools were smaller in size and of higher density than those from the Cantabric area. These differences could be related to the facts that the Rías Baixas is a nursery zone and sardine length and age are smaller than in the Cantabric Sea. It would seem that the differences in school morphology and energetic characteristics related to length and age of individuals allow us to distinguish between the sardine echo traces in this area. There is a high annual variability in the number of schools and this is not a function of either survey design or strategy and it is not related to the abundance estimates of sardine. These results are important for both future species identification and the improvement of survey design and strategy.

Keywords: acoustics, sardine, school, Spanish-Atlantic, temporal and spatial variability.

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Introduction

The sardine (*Sardina pilchardus*, Walbaum 1792) in Atlantic Iberian waters has supported one of the oldest fisheries of the Spanish-Atlantic coast. The earliest documents of Spanish skippers date from the 14th century (Ferreira, 1998). Nowadays the sardine fishery still uses traditional methods and has considerable social and economic overtones. Because of its importance, a specific research project to study the biology and dynamics of this population was set up that included direct abundance estimates by acoustic methods.

In 1983 Spain began to conduct acoustic surveys in the Atlantic waters off the Iberian Peninsula, focusing on the sardine. Since 1986 these surveys have been conducted in the spring, during the spawning period of this species (Ré *et al.*, 1990; Solá *et al.*, 1990). Like most pelagic fish species, the sardine occurs mainly in schools. This kind of spatial distribution can be measured by means of echosounders. Via the school database compiled from the acoustic-survey data, echo traces were assigned to fish species following a procedure that was based on the proportion of fish found at the trawl hauls. However, a learning process was also used which consisted of relating the shape and energy characteristics of the school and its location (i.e. geographical location, distance from the coast, sea bottom typology among others) to fish species.

Over this period, the trend in Spanish sardine catches exhibited a sharp decrease with landings in 1985 of around 100 000 tonnes falling in the late 1990s to about 3000 tonnes. This trend was also observed in the acoustic survey time-series (Carrera and Porteiro, 2003). The changes in stock size occurring not only in sardines but also in anchovies were associated with a reduction in their lifespan as well as in their migration range (Lluch-Belda *et al.*, 1989, 1992).

This paper examines the spatial, temporal and morphological variability of sardine-school parameters found during the Spanish acoustic surveys carried out from

1992 to 1997 (except 1994), in order to facilitate the identification of sardine schools and to improve the accuracy of acoustic surveys by taking into account the schooling behaviour of the species.

Material and methods

Acoustic sampling

Five acoustic surveys carried out in the Northwestern and North Atlantic waters off the Iberian Peninsula, in the years 1992, 1993, 1995, 1996 and 1997 were analyzed. The surveys were carried out in March and April, coinciding with the spawning period of the sardine in the area (García *et al.*, 1991). The survey design and strategies are described in Porteiro *et al.* (1996). The number of nautical miles (nmi) surveyed varied every year. In 1992 and 1993 the survey design was that of a grid with zigzag transects while for the other surveys, the area was covered using parallel transects perpendicular to the coast. Moreover, although the surveyed area covered the whole continental shelf, in 1992, 1993 and 1997 the surveys also extended over blue whiting (*Micromesistius poutassou*, Risso 1826) distribution up to 1000-m depth or more (1754 m) if blue whiting occurred further offshore as shown in Figure 1.

The acoustic equipment was a SIMRAD EK-500 echosounder working at 38 kHz calibrated prior to each survey. A PC controls all the general features of the echosounder such as the automated change of the scales, GPS-signal recognition and integration-value outputs by layer and elementary distance sampling unit (EDSU), expressed as the nautical area scattering coefficient (NASC) or s_A values (m^2/nmi^2). The survey speed was 10 knots and the EDSU was 1 nmi. The acoustic track was recorded on both day and night and the sampling procedure was evenly distributed according to time. The acoustic data are available on paper recorded at a normal threshold of −70 dB. The integram line (a graph of the accumulated echo integral against time) was also recorded at −80 dB threshold.

School database

Throughout the surveyed area sardines were seen either in schools or in other aggregation patterns like dispersed layers but we only examined those structures corresponding to schools. Schools were allocated into fish species after examining the echograms. This was done based on our experience with echo traces (i.e. shape, density, bottom typology and depth etc), which was corroborated by the trawl hauls. The non-trawled echogram images were aggregated to the previously defined group of images based on the characteristics of their echo traces.

The schools were directly extracted from the echograms using a semi-automated method. Echograms were scanned and the digitized images were processed with commercial software (i.e. Corel Draw and Autocad LT). The image of each school was re-scaled in order to get the true proportion between axes. From each school several parameters were measured: morphological (school height, school length, school area and school perimeter), positional (school depth, bottom depth under school and distance from the coast), energetic (energy, s_A value, and density, s_A/area), and temporal (time of occurrence of the school). Morphological variables were corrected as described in Diner (2001). The geographical position was derived from the GPS recorders at the beginning and end of each nautical mile assuming straight-line navigation and a constant ship speed. The total echo-integrated energy was assumed to be equal to the integram line. Oceanographic variables (temperature and salinity) were compiled from the nearest CTD station using the values obtained at the same depth as that of the school.

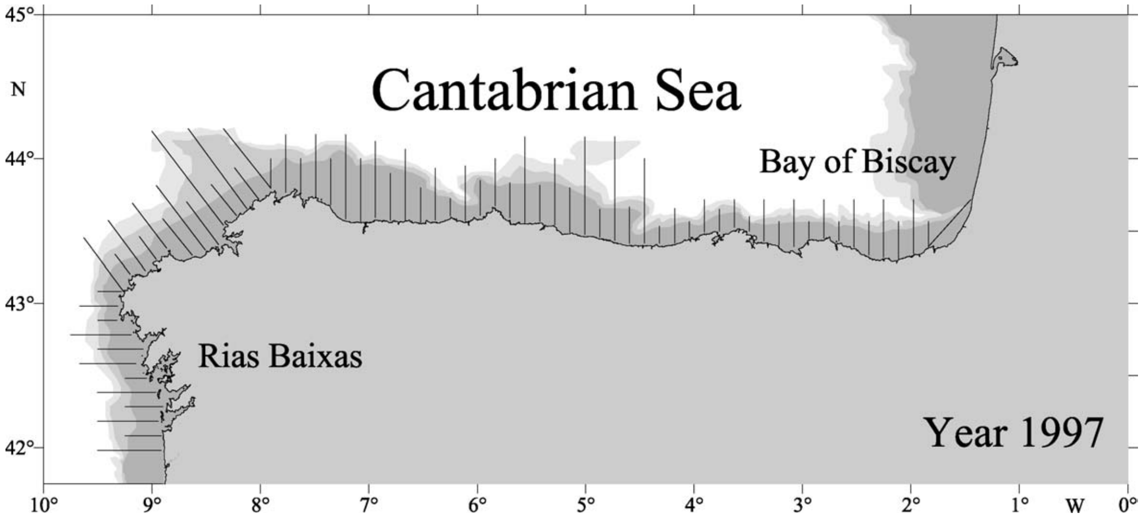

Figure 1. The area surveyed in 1992, 1993 and 1997 with acoustics tracks. The 200, 500 and 1000-m isobaths are shown.

School distance from the coast was computed as the normal minimum distance from the coastline (extracted from the GEBCO using a high resolution) to a particular school.

This semi-automated procedure was tested using a fully automatic system. For this purpose, data from the 1997 acoustic survey were stored and post-processed with Sonar-Data Echoview, applying the school detection algorithm.

Data analysis

The sardine schools were divided into two geographical areas. The southern extending from the Spanish–Portuguese border to 43°N latitude (Rías Baixas) and the more northerly, the Cantabrian Sea, from 43°N to the inner part of the Bay of Biscay (Figure 2). The first of these is characterized by the presence of wide (8 nmi) estuaries

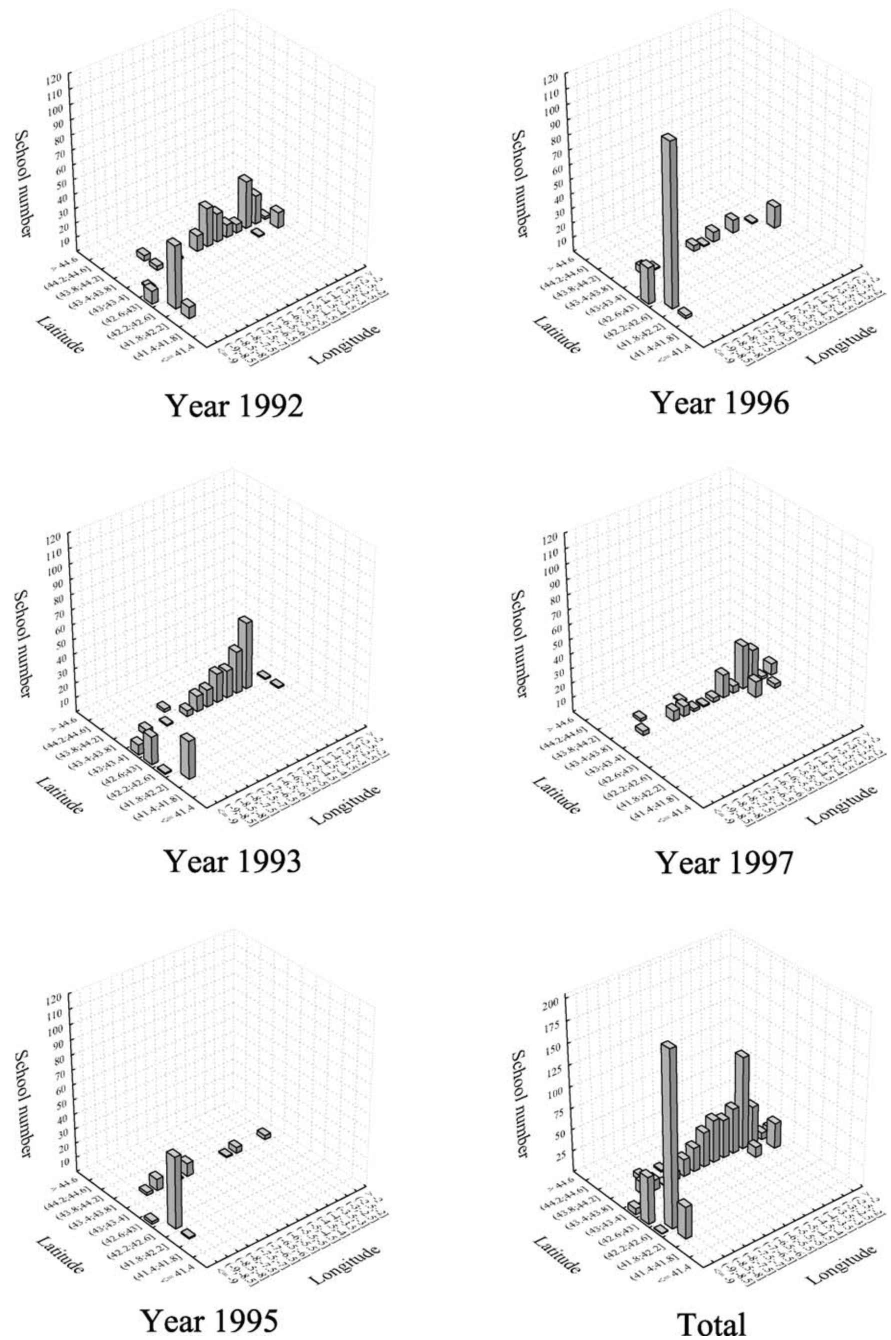

Figure 2. The number of schools by years and the total number located by latitude and longitude.

around 20-nmi long in which most of the sardine schools occur.

The school parameters were described using both univariate and multivariate analyses. The relationship among school parameters was analyzed by a principal component analysis (PCA; Anderson, 1958; Lebart *et al.*, 1995) performed each year. For these purposes, all parameters except temperature and salinity were log-transformed to meet the assumptions of normality. The variables were grouped according to the PCA results and further analyses were carried out using a single variable from each group. Box-plots were used to characterize each selected parameter by area and year. Spatial and temporal interactions were analyzed by multivariate analysis of variance (MANOVA) procedures while the analysis of variance (ANOVAs) approach was carried out to test inter-annual differences in each area and spatial differences each year except for 1997 when no sardine schools were located in the Rías Baixas. Discriminant analysis, employing forward-stepwise selection of variables, was carried out to determine the parameters that best discriminated between years and areas. Finally, ANOVAs were also performed to compare the time of school occurrence between years and the two areas.

Results

The total number of pelagic schools detected during the five surveys was 2065, with 798 judged to be sardine (39%) (Table 1). A slight decrease was detected in the total number of pelagic schools from year-to-year and the number of pelagic schools per nautical mile was higher in 1995 and 1996 (0.74 and 0.56, respectively), with the main occurrence of schools on the continental shelf (Table 1). The surveys exhibited a high annual variability in the number of sardine schools detected every year, representing between 20 and 50% of the total detected schools. The annual number of schools would appear to be independent of the sampling intensity as well of the total annual sardine-biomass estimate (Table 1).

Of the total number of sardine schools detected during all surveys, 35% of the schools occurred in the Rías Baixas and 65% in the Cantabric zone (Table 1) with a pronounced variability observed in both their annual and geographical occurrences. While the years 1992, 1993 and 1995 showed similar percentages of sardine schools for each area, 1996 and 1997 showed very different percentages. In 1996, 75% of sardine schools were detected in the Rías Baixas area and 25% in the Cantabrian zone, while in 1997 no sardine schools were detected in the Rías Baixas region (Figure 2, Table 1).

The PCAs carried out on the school parameters showed very similar results for each year (Figure 3). In all cases the first three axes extracted explained more than the 72.7% of the total variance. Axis I accounted for more than 40% of the total variance for each year, and contrasted mainly the morphological variables of schools (all of them were highly correlated) with the school density and temperature (Table 2). Axis II explained more than 16.7% of the total variance for each year and contrasted energetic variables (energy and density) with location variables (i.e., school and bottom depth; distance from the coast) (Table 2). Finally, the third axis (more than 10.6% of the total variance) was highly correlated with salinity (Table 2) in all years except 1997. So, two main groups of variables were observed each year with PCAs: one of morphological variables (school length, height, area and perimeter) and other of the positional variables (school and bottom depth and distance from the coast), while the other variables were more dispersed (Figure 3). Because of the high correlation observed in the morphological and positional variables, school area and school depth, respectively were selected, as representatives of each group, in order to perform further analysis. Temperature, salinity, school density and school energy were employed as well.

Figure 4 shows the Box-plot performed on the selected parameters. There was a high variability between years and zones, with the most important differences found in the temperature and salinity data. Sardine schools preferred a depth between 20 and 50 m in both areas, although the Cantabrian schools appeared to have a more expanded location. The morphology of the schools represented by the school-area parameter exhibited substantial differences in the two geographical areas, with the sardine schools from

Table 1. The total number of miles in the acoustics tracks, the total school number (all species), the number of sardine schools located, and the sardine biomass estimated by years and geographical areas.

							No. of sardine schools				
	NMI surveyed	No. of pelagic schools	No. of sardine schools	Sardine schools %	Total schools/nmi	Sardine schools/nmi	Rías Baixas	%	Cantabric Sea	%	Sardine biomass (ktonnes)
Year 1992	1443	487	209	42.92	0.34	0.14	61	29.19	148	70.81	45.31
Year 1993	1627	524	203	38.74	0.32	0.12	53	26.11	150	73.89	183.08
Year 1995	542	400	80	20.00	0.74	0.15	28	35.00	52	65.00	17.08
Year 1996	663	370	181	48.92	0.56	0.27	138	76.24	43	23.76	55.20
Year 1997	1088	284	125	44.01	0.26	0.11	0	0.00	125	100.00	48.37
Total	5363	2065	798	38.64	0.39	0.15	280	35.09	518	64.91	349.04

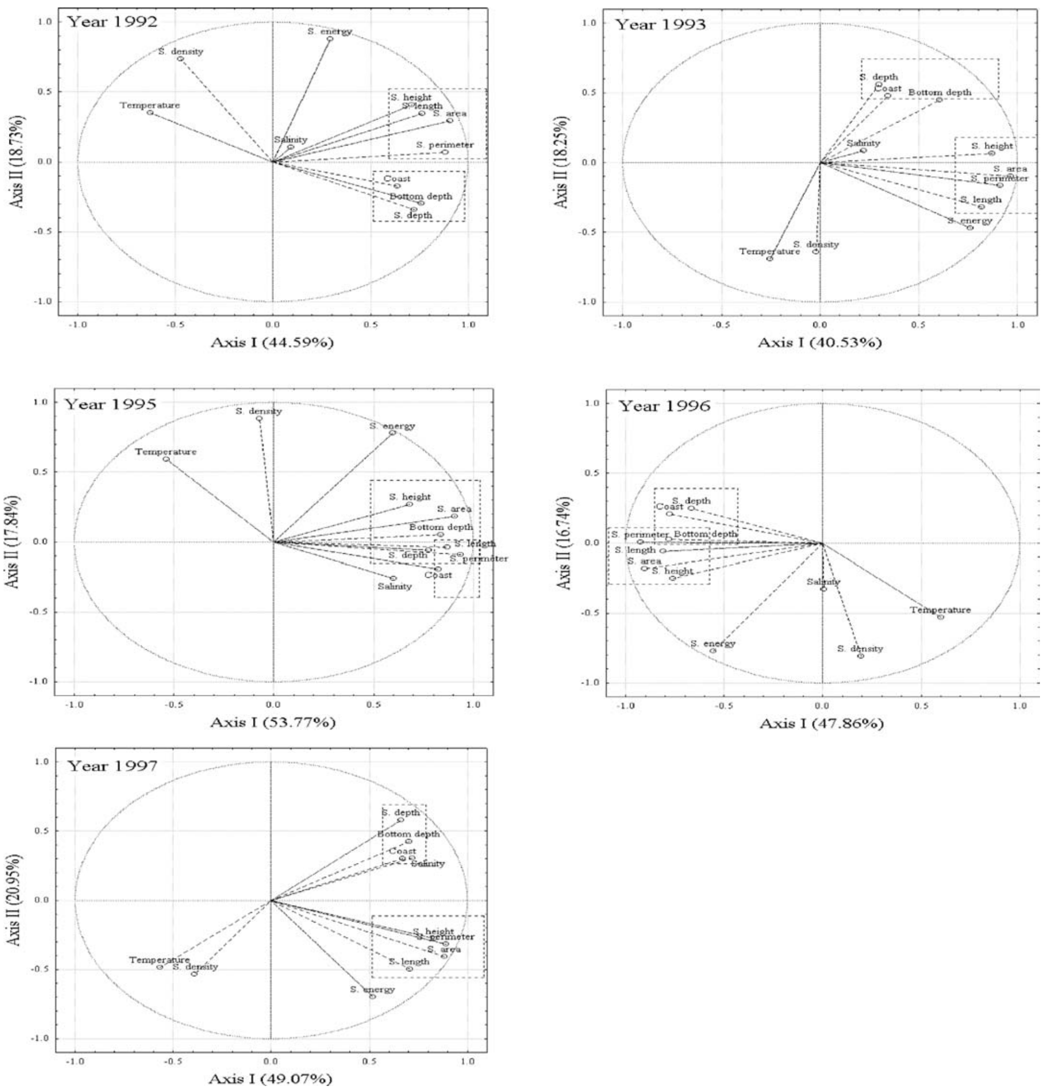

Figure 3. Principal component analysis by years. Position of the variables on the axis I/II. The enclosed dotted lines show highly correlated variables.

the Rías Baixas being smaller than those detected in Cantabria. In contrast, school energy was slightly higher in the Rías Baixas than in the Cantabrian Sea and there was an apparent tendency for school energy to decrease in the former area while it increased in the latter over the years (Figure 4). School density was higher in the schools located in the Rías Baixas than those located in the Cantabrian Sea. Water temperature tended to increase over the time-series, with 1992 standing out as the coldest year.

Temporal and spatial interactions were found (MANOVA, $P < 0.001$). Although general school descriptors would appear to be more stable in the Cantabrian Sea than in Rías Baixas (Figure 4), significant inter-annual differences were found in both areas (ANOVA, $P < 0.001$). In the Rías Baixas, inter-annual differences were found between 1993 and every one of the other years (Tukey, $P < 0.01$), while in the Cantabric Sea they were found between years 1992 and 1993, 1992 and 1997 and 1996 and 1997 (Tukey, $P < 0.01$). Significant spatial differences (ANOVAs, $P < 0.001$) were found in all years.

Discriminant analysis carried out in each area indicated that 86.5% schools from the Rías Baixas and 67% from the Cantabric Sea could be classified correctly to respective years (Table 3). In both areas, the first discriminant function was strongly correlated with temperature, and mainly discriminated year 1992 (with the lowest temperature of the series) from the other years (Table 3; Figure 5). In Rías Baixas, the second function was highly correlated with salinity and the third function was correlated with school depth and school area (Table 3). In the Cantabric Sea,

Table 2. Principal components analysis. The loadings of the first three axes for each year and all years together. Eigenvalues and the percent of variance explained are given. More significative correlations are shown in bold.

	Year 1992			Year 1993			Year 1995			Year 1996			Year 1997			All years		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
Coast distance	**0.64**	−0.17	−0.26	0.34	0.48	**−0.73**	**0.82**	−0.20	−0.06	**−0.77**	0.21	0.03	**0.67**	0.30	−0.18	**0.64**	0.18	−0.49
School depth	**0.72**	−0.34	−0.44	0.30	0.56	0.33	**0.78**	−0.06	−0.45	**−0.67**	0.25	0.53	**0.66**	0.58	−0.13	**0.58**	0.44	0.29
School length	**0.77**	0.35	0.19	**0.82**	−0.32	0.12	**0.87**	−0.04	0.14	**−0.81**	−0.06	−0.04	**0.71**	−0.50	0.28	**0.80**	−0.26	0.01
School height	**0.71**	0.41	0.05	**0.87**	0.06	0.01	**0.68**	0.27	0.56	**−0.76**	−0.25	−0.24	**0.83**	−0.28	0.06	**0.81**	−0.23	−0.01
School area	**0.91**	0.29	0.18	**0.96**	−0.10	0.05	**0.91**	0.18	0.35	**−0.90**	−0.18	−0.18	**0.88**	−0.41	0.16	**0.93**	−0.23	−0.01
School perimeter	**0.88**	0.07	0.22	**0.91**	−0.17	0.14	**0.94**	−0.09	0.15	**−0.92**	0.01	−0.04	**0.89**	−0.32	0.22	**0.91**	−0.11	0.03
School energy	0.29	**0.88**	−0.11	**0.76**	−0.47	−0.12	0.60	**0.78**	−0.10	−0.56	**−0.77**	−0.16	0.52	**−0.70**	−0.48	0.48	**−0.80**	0.14
School density	−0.47	**0.73**	−0.20	−0.02	−0.64	−0.25	−0.07	**0.88**	−0.38	0.19	**−0.81**	−0.09	−0.39	−0.54	**−0.73**	−0.36	**−0.77**	0.14
Bottom depth	**0.76**	−0.30	−0.36	**0.61**	0.45	−0.43	**0.84**	0.05	−0.16	**−0.78**	0.03	0.38	**0.70**	0.42	−0.24	**0.75**	0.26	−0.18
Temperature	**−0.63**	0.35	−0.36	−0.25	**−0.69**	−0.22	−0.54	0.59	0.05	0.60	−0.53	0.29	−0.57	−0.49	0.38	−0.48	−0.47	−0.17
Salinity	0.09	0.11	**−0.82**	0.22	0.09	**0.73**	0.60	−0.26	**−0.62**	0.01	−0.33	**0.86**	0.72	0.30	−0.04	0.18	0.17	**0.89**
Eigenvalue	4.91	2.06	1.37	4.46	2.01	1.54	5.91	1.96	1.24	5.26	1.84	1.38	5.40	2.30	1.17	4.94	1.97	1.22
% Variance	44.59	18.73	12.45	40.53	18.25	13.98	53.77	17.84	11.27	47.86	16.74	12.54	49.07	20.95	10.61	44.93	17.87	11.08

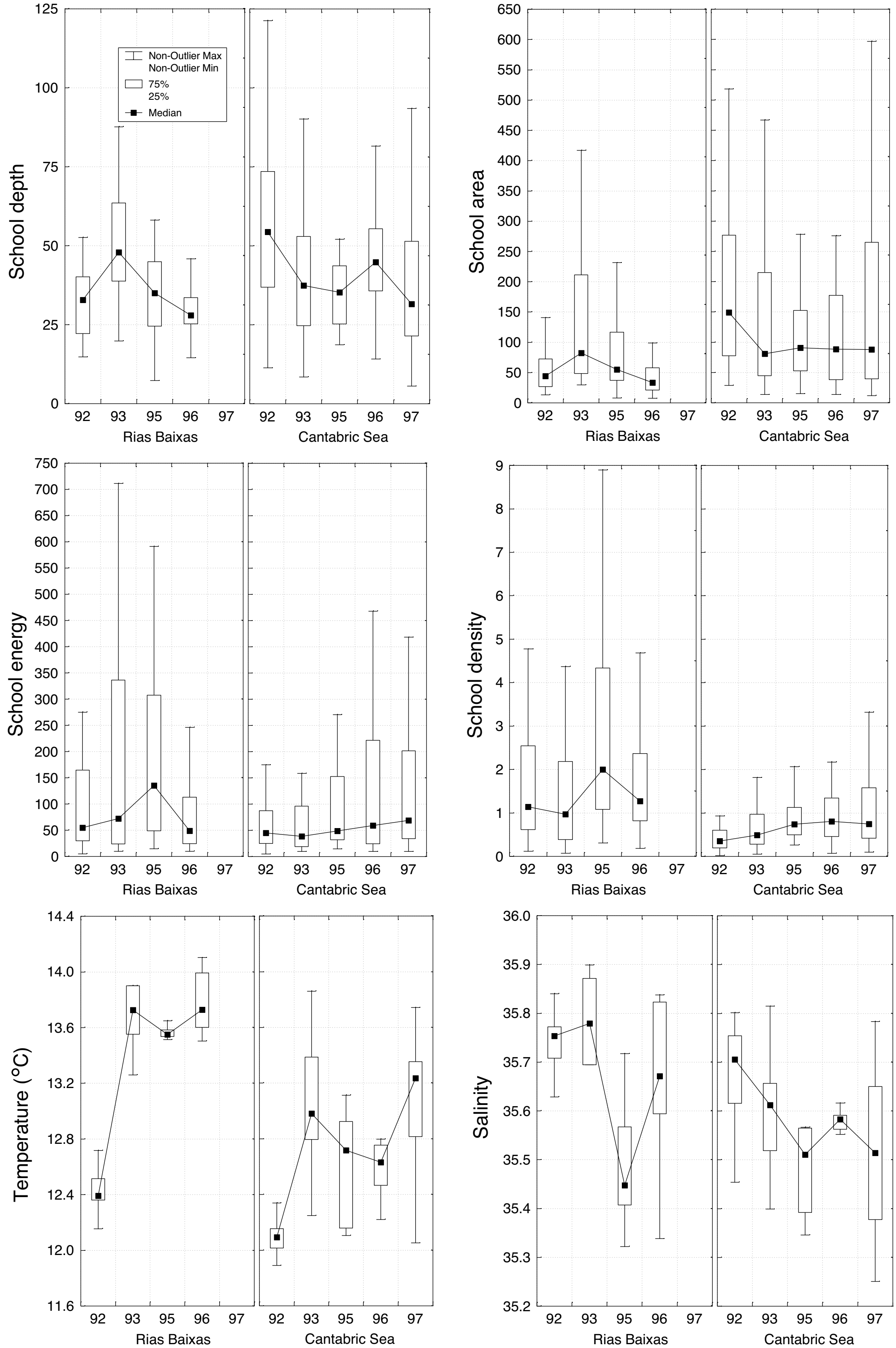

Figure 4. Box-plots of the selected variables (school depth, school area, school energy, school density, temperature (°C) and salinity) related to the different years in the two geographical areas.

Table 3. Discriminant-analysis results from the analysis of the PCA-selected variables for Rías Baixas and Cantabric Sea: (A) discriminant analysis between years in each area; (B) discriminant analysis between areas each year. The variables shown are those remaining in the model forward-stepwise selection. The F-statistic and the associated p-value are indicated for each variable. Factor-structure coefficients of the discriminant functions (i.e., the correlations of discriminant functions with each variable) are also given, with bold indicating coefficients >0.75.

Variable	F	p-Value	Function 1 coefficients	Function 2 coefficients	Function 3 coefficients
(A) Discriminant analysis between years					
Rías Baixas					
Temperature	617.31	<0.001	**0.77**	−0.42	−0.37
Salinity	50.39	<0.001	−0.05	−**0.83**	0.38
School depth	89.01	<0.001	0.03	−0.05	**0.77**
School area	9.42	<0.001	0.00	0.11	**0.75**
School density	7.26	<0.001	0.01	0.29	−0.31
Cantabric Sea					
Temperature	242.0299	<0.001	**0.84**	0.05	−0.28
Salinity	24.8747	<0.001	−0.23	−0.13	**0.82**
School depth	9.2615	<0.001	−0.18	−0.12	−0.10
School density	9.8095	<0.001	0.18	**0.82**	−0.02
School energy	1.4182	0.227	0.06	0.43	0.26
School area	4.5552	0.001	−0.08	−0.18	0.39

	Rías Baixas	Cantabric Sea
Year 1992	100.00	99.32
Year 1993	62.26	64.67
Year 1995	82.69	0.00
Year 1996	91.30	41.86
Year 1997	–	55.20
Overall	86.51	67.00

	F	p-Value	Function 1 coefficients
(B) Discriminant analysis between areas			
Year 1992			
Temperature	286.97	<0.001	**0.78**
School area	168.90	<0.001	−0.40
School energy	129.62	<0.001	0.04
Salinity	103.38	0.003	0.22
School depth	84.88	0.040	−0.34
School density	76.00	0.001	0.39
Year 1993			
Temperature	113.78	<0.001	**0.21**
Salinity	429.22	<0.001	0.13
School depth	878.94	<0.001	0.05
Year 1995			
Temperature	145.29	<0.001	**0.59**
Salinity	180.94	<0.001	0.00
School depth	135.36	<0.001	−0.06
Year 1996			
Temperature	1128.25	<0.001	−**0.85**
Salinity	765.04	<0.001	−0.10
School energy	514.92	<0.001	0.04

	Rías Baixas	Cantabric Sea	Overall
Year 1992	91.8	99.3	97.1
Year 1993	100.0	99.3	99.5
Year 1995	100.0	96.4	98.8
Year 1996	100.0	100.0	100.0

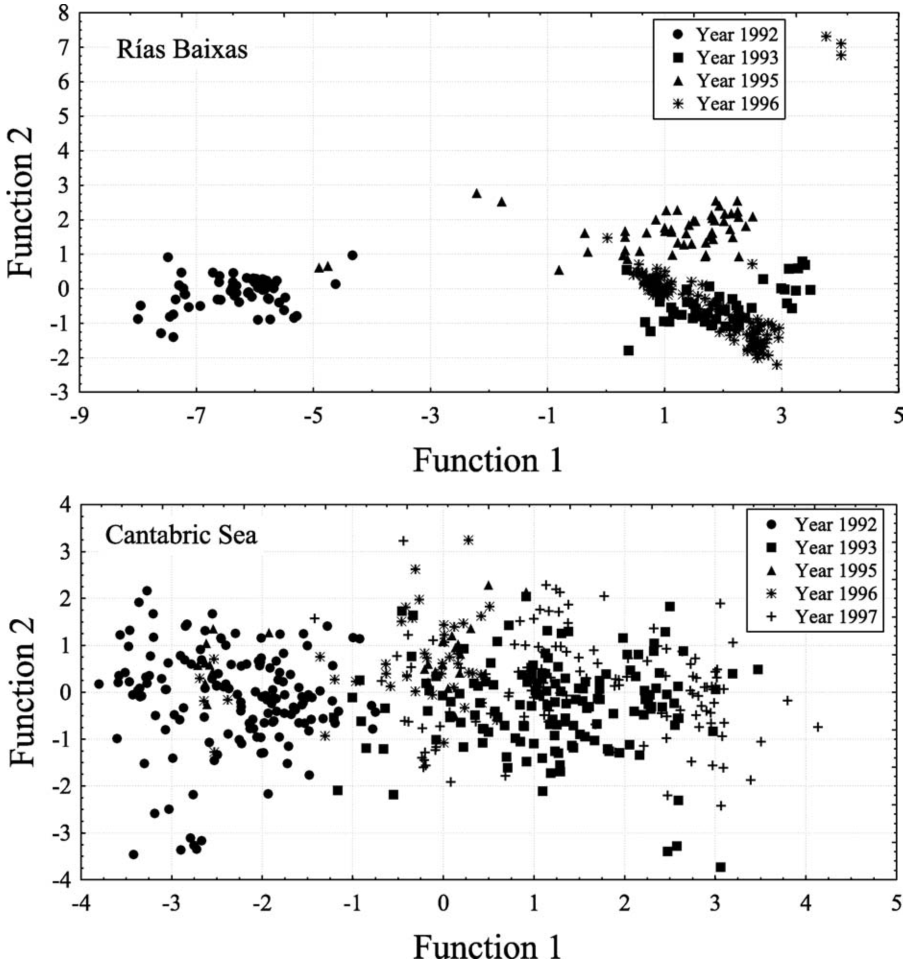

Figure 5. Discriminant-function analysis scores plotted by years in both geographical areas.

school density (second function) and salinity (third function) were the highly correlated variables (Table 3).

While the sampling intensity was similar according to time-of-day, significant annual and geographical differences were found in the time of occurrence of the schools. Although most of the schools occurred during the daytime in all years as well in both areas (Figures 6 and 7), there were significant differences in the time of occurrence between years (ANOVA, $P < 0.001$) and between areas (ANOVA, $P < 0.001$). The pairwise comparisons between years showed significant differences (Tukey, $P < 0.005$) between years 1992, 1993 and 1996 and years 1995 and 1997 with both having the lowest number of schools.

Discussion

The sardine, like most pelagic fishes, exhibits an aggregate behaviour by forming schools. An analysis of the Spanish acoustic surveys performed off the Atlantic coast of the Iberian Peninsula in spring from 1992 to 1997 (except 1994) reveals a high annual and geographical variability in occurrence and morphology of the sardine schools. A high annual variability in sardine biomass has been reported during the 1991–2001 period in this same area, and the reasons for this variability stem from several causes e.g., climate, fish behaviour, anthropogenic, etc. (Porteiro *et al.*, 1996; Carrera and Porteiro, 2003). However, the school number would appear to be unrelated to either the total-biomass estimate or the sampling intensity. Several authors have not found a discernible relationship between stock abundance and the number of schools of pelagic fish (Petitgas and Levenez, 1996; Aukland and Reid, 1998; Petitgas *et al.*, 2001).

Considerable differences were found between the length distribution and the age of the sardine populations in the two areas where sardines are found off the Spanish coast (Table 4) (Carrera and Porteiro, 2003). Younger fish are chiefly located close to the Spanish–Portuguese border and there is an age-gradient from this area towards the inner part of the Bay of Biscay, where most of the older fish are

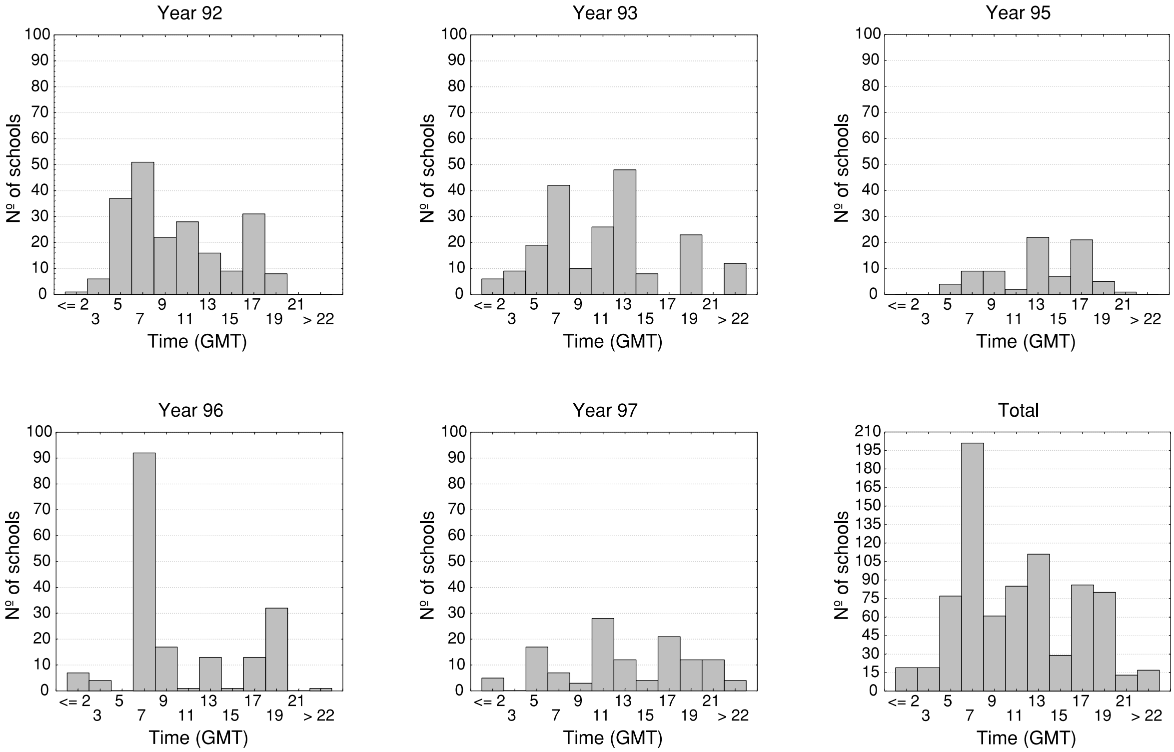

Figure 6. "School number" located during the daytime by years and total.

found (Porteiro *et al.*, 1996). This different age pattern might explain the differences found in school size and density, as well as in the number of schools and time of occurrence of the schools, between the two areas. Differing school size could be attributed to the different mean length of the fish that make up the school, given a fish's preference for the company of individuals matching in body size (Pitcher, 1993). A different behaviour linked to different specific preferences due to age or size is also a possibility. A species-specific preference in the vertical distribution has been reported for other pelagic species in the Bay of Biscay (Scalabrin and Massé, 1993; Massé *et al.*, 1996) and the sardine appears to follow a similar pattern, with a depth preference in the range of 20–50 m.

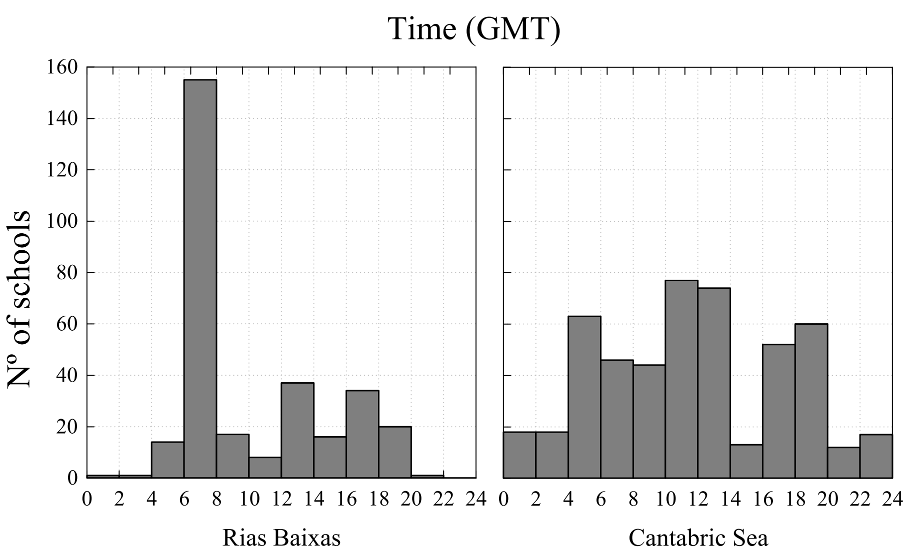

Figure 7. "School number" located during the daytime by geographical areas.

Table 4. The mean length and mean age of the sardines by years and geographical areas.

	Rías Baixas		East Cantabrian	
	Mean length	Mean age	Mean length	Mean age
Year 1992	18.15	1.87	21.53	4.53
Year 1993	18.35	1.68	22.84	6.48
Year 1995	19.54	2.97	22.19	4.29
Year 1996	20.61	3.75	21.82	4.03
Year 1997	19.69	3.05	20.68	3.00

Nevertheless, all the morphologic variables of the schools were highly correlated and even though the size of the sardine schools differed between areas, the shape and morphological relationship were, in general, quite similar (Muiño *et al.*, 2003). There may be a specific species–shape relationship in the sardine schools that could offer greater advantages (hydrodynamics, predation, reproduction, etc.) to each individual. Many studies have been done on the most advantageous school size and shape and the possible factors at work in each case (Fréon and Misund, 1999).

The inter-annual and spatial variability observed in each zone was mainly due to temperature. To a lesser extent, salinity, school area and school depth also explained the temporal variability observed in the Rías Baixas, while in Cantabric Sea the factors were school density and salinity. Discriminant-function analyses carried out year-to-year were able to classify the school in each area in >97% of cases, and in all years the first discrimination function was mainly correlated with temperature (Table 3). Temperature was the more important factor to explain temporal and spatial variability (Lluch-Belda *et al.*, 1992; Lee *et al.*, 1995).

The inter-annual variability observed in each zone between school occurrence and time might be related to the annual cycle of temperature and salinity change. Significant spatial differences may be attributed to the fact that in the Rías Baixas region most of the schools were observed at sunrise while in the Cantabrian Sea during all daylight hours the schools seemed to occur with similar probability (Figure 7). Differences in the mean length and age between both areas (Table 4) might explain all these differences but differences in temperature and salinity are difficult to explain.

Although some characteristics can be observed in each area or for a particular year, no general pattern of the occurrence of sardine schools on the Spanish-Atlantic coast can be found. Multivariate analyses revealed great complexity in the variability of the number and morphology of the sardine schools. Apparently, neither year, zone nor oceanographic variables have any direct impact on school occurrence, and this might stem from the interaction between different factors whose relative incidence might vary each year. In this context, further analysis would seem to be needed.

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