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Note

Spatio-temporal patterns and morphological characterisation of multispecies pelagic fish schools in the North-Western Mediterranean Sea

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Abstract

Echosounder data from four surveys (1992, 1993, 1995 and 1996) is used to investigate the spatio-temporal variability of school behaviour in North-Western Mediterranean waters. The schools are described using morphological, energetic, spatial and temporal descriptors. The variability in the morphological, positional and energetic parameters of the schools is attributable more to the size of the school's individuals (juveniles or adults) than to the relative composition (percentage) of pelagic species in the area. This fact made difficult the identification of species in the studied area. The concentration of schools in certain geographic zones is determined by local oceanographic characteristics that favour the trophic or reproductive activity of these species. The diurnal aggregative behaviour of pelagic species is typical of the zone and no schools were detected at night. The biomass of the pelagic species in the area under consideration has diminished during the 4-year study period and no relationship was found between the number of schools and the biomass evaluated. This is the first time that the schools of small pelagic fishes from the Spanish Mediterranean Sea have been described and the information could be useful to the management and exploitation of the fisheries in the area.

Keywords: Pelagic schools; Morphological description; Fish behaviour; Mediterranean Sea

1. Introduction

The estimation of pelagic fish biomass from acoustic surveys is based on the proportionality that exists between the back-scattered acoustic energy measured and the number of fish in the area sampled (Dragesund and Olsen, 1965). Acoustic surveys carried out in the Spanish Mediterranean shelf are aimed primarily at obtaining abundance estimates of anchovy (*Engraulis encrasicholus*) and sardine (*Sardina pilchardus*), although this area is also characterised by several other pelagic species, such as the sardinella (*Sardinella aurita*), horse mackerel (*Trachurus mediterraneus, Trachurus picturatus* and *Trachurus trachurus*), bogue (*Boops boops*), mackerel (*Scomber scombrus*) and chub mackerel (*Scomber japonicus*). Most of these pelagic species form schools during the day for purposes related to feeding, defence or reproductive activities (Pitcher, 1993; Fréon and Misund, 1999). The morphology, internal structure and spatio-temporal distribution of these schools is highly variable (Scalabrin and Massé, 1993; Massé et al., 1996; Petitgas and Levenez, 1996; Petitgas et al., 2001; Muiño et al., 2003). These factors affect abundance estimation using acoustic surveys, therefore, if we were able to broaden our knowledge of them from the study of the unprocessed school data from echograms, it would be possible to improve discrimination between different species, thereby resulting in more accurate biomass estimates. This paper presents a description of inter-annual variability in the spatio-temporal distribution, morphology and internal structure of the schools and examines the possible causes of this variability.

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2. Materials and methods

2.1. Acoustic sampling

Four acoustic surveys were carried out in the North-Western Mediterranean waters, off the Iberian Peninsula in 1992, 1993, 1995 and 1996. Survey design and strategies are described (see Abad et al., 1998a,b). The acoustic surveys were performed on the continental shelf between the 30 and 200 m isobaths, in the area between Cape Cervera on the French border and Cape Oropesa (Fig. 1). The sampling grid consisted of zigzag transects, 10 nautical miles (nmi) apart. The elementary distance-sampling unit (EDSU) is the nautical mile. The surveys took place between October and November in order to detect anchovy recruitment (Palomera, 1986, 1991, 1992). The period also coincides with the beginning of the sardine spawning season (Larrañeta, 1981). The acoustic equipment consisted of a calibrated Simrad EK-500 echosounder–echointegrator operating at 38 kHz. A PC controls all the general features of the echosounder such as automated scale changes, Ground Positional System (GPS) signal recognition and outputs integration value by layer and EDSU. The integration values are expressed as nautical area scattering coefficient (NASC) units or s_A values ($m^2 \times nmi^{-2}$) (MacLennan et al., 2002). The survey speed was 10 knots and the acoustic track was surveyed by both day and night, except during the 1996 survey when acoustic data acquisition was restricted to day-time. Acoustic data are available in the form of printed paper recordings at a normal threshold of –70 dB. The integram line was also recorded at a threshold of –80 dB.

2.2. School database

Echograms were scanned and the digitised images were processed with commercial software (i.e. Corel Draw and Autocad LT). The image of each school was re-scaled in order to obtain the true proportion between axes. Several descriptors were extracted directly from each school and were divided into the following four categories:

1. Morphological (school length (m), height (m), area (m^2) and perimeter (m)).
2. Positional (school depth (m), bottom depth under school (m) and distance of the school from the coast (nmi)).
3. Energetic (school energy (s_A) and school internal density (s_A/school area)).
4. Temporal (time of occurrence (GMT, Greenwich Mean Time)).

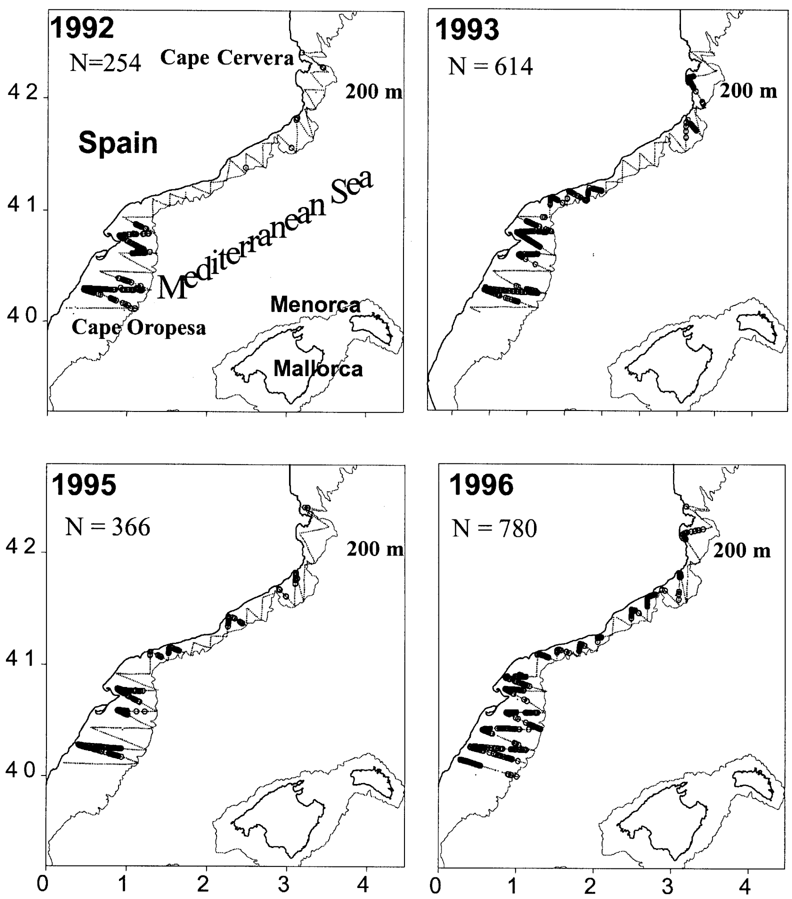

Fig. 1. Survey design (zigzag) followed during cruises and schools detected every year in the studied area, North-Western Mediterranean Sea, from Cape Cervera to Cape Oropesa.

Table 1
Number of nautical miles analysed by year, number of corrected schools and total school energy (s_A) detected in the acoustic surveys carried out in the North-Western Mediterranean Sea

	Year			
	1992	1993	1995	1996
Miles analysed	569	603	591	589
School number	254	614	366	780
Total school energy (s_A) ($\times 10^2$)	46 515	121 970	56 154	98 768
School mean energy (s_A/number of schools)	18 313	19 865	15 343	12 663

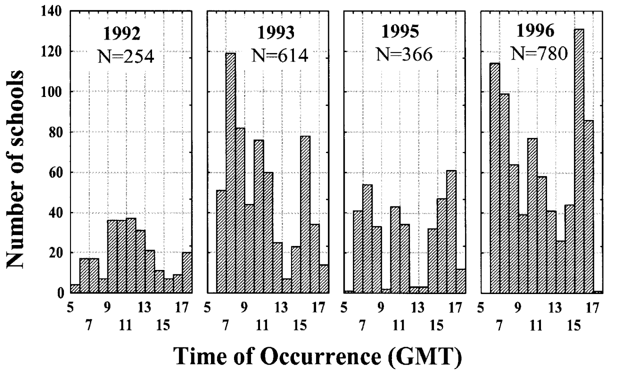

Fig. 2. Time of occurrence (GMT) of schools detected every year in the studied area. *N*: number of schools.

Since accurate measurements of school geometry and density can only be properly derived when the ratio between school size at a particular depth and the transducer beam width is greater than 1.5, morphological variables such as length, height and area were corrected as described by Diner (2001). The geographical position, derived from the GPS, was recorded at the beginning and at the end of each nautical mile assuming straight-line navigation and constant ship speed. School distance from the coast was computed as a normal minimum distance from the coastline to a particular school. Coordinates were extracted from the General Bathymetric Chart of the Oceans (GEBCO) at high resolution. The total echo-integrated energy of the school was assumed to be equal to the integram line, considering only values equal to or greater than 5 m^2 of echo-integration.

2.3. Data analysis

Only corrected schools by Diner's algorithm were used in the analyses (Diner, 2001). Simple descriptions were done using box-plots done on each variable for each survey. Because the "time of occurrence" distributions were not normal, a Kruskal–Wallis test was performed to test significant temporal differences between years and a Kolmogorov–Smirnov test was done in order to compare the distributions of "time of occurrence" between pairs of years. The rest of the variables were examined using an analysis of variance (ANOVA) to test for inter-annual differences. The Tukey multiple comparison test was also performed to make paired comparisons between years for those variables showing significant inter-annual differences ($P < 0.05$).

3. Results

The number of schools detected annually and the summed energy (s_A) of these schools exhibited a high degree of inter-annual variability (Table 1), despite the fact that a similar number of miles were sampled each year. High number of schools did not coincide with a summed school energy. The mean school energy (total s_A/number of schools) was similar between 1992 and 1993, while this figure dropped gradually in subsequent years (Table 1).

3.1. Morphological variables

All the morphological variables of the schools were characterised by high annual variability (Fig. 3) and significant inter-annual differences (ANOVA, $P < 0.001$). The paired comparisons carried out using each of the morphological variables indicated that only 1992 differed significantly from the rest of the years, while the years 1993, 1995 and 1996 did not show any significant differences between them (Tukey, $P > 0.05$). These annual differences in school size were evident in all the variables analysed (length, height, area and perimeter), being the morphological variables of the schools strongly correlated ($r > 0.65$). The year 1992 had the largest schools on average compared to other years, particularly 1993, when the schools were the smallest on average (Fig. 3, Table 2).

3.2. Positional variables

Most of the schools occurred around the Ebro Delta (between 41° and 40°N) (Fig. 1), although there was high inter-annual variability in school abundance (Table 1). In 1992, the year in which the fewest schools were recorded, schools were clustered in the proximity of the above geographic zone, while in years when a larger number of schools were recorded (1993, 1995 and 1996), the schools tended to spread out, mainly northwards (Fig. 1).

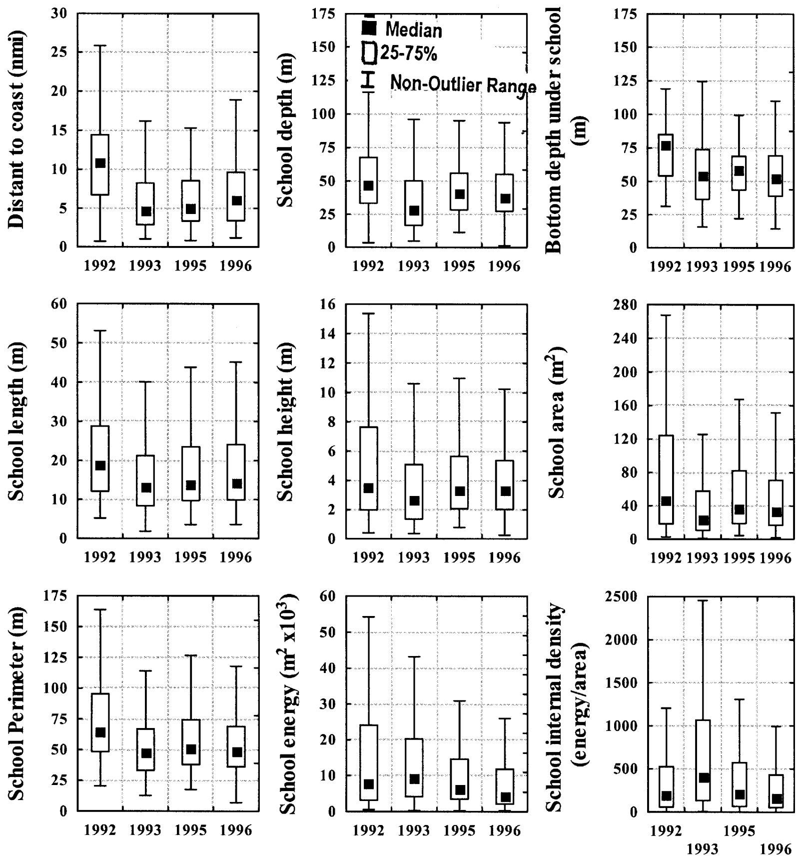

Fig. 3. Box plots of the positional, morphological and energetic descriptors of the schools detected every year.

There were significant inter-annual differences in the distance from the coast (nmi) at which the schools were detected (ANOVA, $F = 50.45$, $P > 0.001$), being highly significant between 1992 and other years (1993, 1995 and 1996), and between 1993 and 1996 (Tukey, $P < 0.001$). In 1992, schools were located further offshore (between 7 and 14 nmi) compared to the rest of the years (between 3 and 10 nmi). Schools were found closest inshore (between 3 and 8 nmi) in 1993 (Fig. 3, Table 2).

The ANOVA points to the existence of significant inter-annual differences in the depth in the water column where schools were detected ($F = 59.76$, $P < 0.001$), with 1993 being significantly different from the other years (Tukey, $P < 0.001$). In 1993, schools were found closer to the surface (between 17 and 50 m) than during the other years (Fig. 3, Table 2). In contrast, schools recorded during the 1992 survey were found at much greater depth (between 33 and 68 m), than in 1996 (Tukey, $P < 0.05$), however, not significantly different from that of 1995.

Although the surveys were all done on the same transects every year, and, therefore, the same bottom depths were sampled, the resulting ANOVA of bottom depths where the schools were detected points to the existence of marked inter-annual differences ($F = 36.63$, $P < 0.001$). Subsequent Tukey test shows that these differences are due to the year 1992 (depth between 54 and 85 m), which again, differed significantly ($P < 0.001$) from the rest of the other years (Fig. 3, Table 2).

3.3. Energetic variables

The two energetic variables analysed (school energy (s_A) and school internal density (s_A/area)) also exhibited significant inter-annual differences (ANOVA, $P < 0.001$). School energy tended to decrease every year, with schools detected in 1992 having the greatest energy; significant differences (Tukey, $P < 0.001$) were also seen between 1993 and the years 1995 and 1996. Internal density of the schools was highest in 1993 (Fig. 3, Table 2) and differed significantly from the other years (Tukey, $P < 0.001$).

3.4. Temporal variables

In 1992, 1993 and 1995 the acoustic surveys were performed over a 24-h period. Nevertheless, only two schools were recorded at night, one in 1992 at 00:30 h GMT and the other in 1993 at 23:50 h GMT. The rest of the schools (1234) were detected between 6 and 18 h GMT (Fig. 2), coinciding with the period between dawn and dusk in the study area. The time at which the schools were detected presented significant

Table 2
Spatial, morphological and energetic descriptors data used to characterise the pelagic schools detected every year. The number of schools detected were 254 in 1992, 614 in 1993, 366 in 1995 and 780 in 1996

Year	Mean	Median	Min.	Max.	S.D.
Distant to coast (nmi)					
1992	11.7	10.9	0.7	32.6	6.8
1993	6.7	4.7	1.0	27.9	5.8
1995	6.7	5.0	0.8	25.9	5.0
1996	7.7	6.0	1.2	34.6	6.0
School depth (m)					
1992	49.3	46.7	3.3	116.3	23.0
1993	33.9	28.3	4.7	114.2	21.1
1995	42.9	40.9	11.3	95.2	16.8
1996	41.8	37.9	1.4	120.9	18.8
Bottom depth under school (m)					
1992	71.5	77.2	31.1	119.0	19.4
1993	58.2	54.7	15.6	189.0	28.7
1995	57.2	58.9	22.0	99.4	18.6
1996	54.7	52.3	14.4	147.8	20.4
School length (m)					
1992	25.2	18.8	5.2	194.3	24.4
1993	18.4	13.1	1.8	148.4	18.3
1995	19.9	13.8	3.6	172.5	17.4
1996	20.1	14.4	3.6	124.1	17.2
School height (m)					
1992	7.3	3.5	0.4	97.1	10.4
1993	4.1	2.7	0.4	31.8	4.2
1995	4.8	3.3	0.8	44.2	4.7
1996	4.4	3.3	0.3	38.9	4.1
School area (m^2)					
1992	204.6	46.7	2.8	8507.6	731.4
1993	58.1	24.0	1.0	1127.8	105.1
1995	88.5	37.3	4.2	2039.9	176.6
1996	67.6	32.4	2.1	1470.5	110.6
School perimeter (m)					
1992	83.2	63.9	20.6	470.7	62.7
1993	57.1	47.7	12.8	338.7	39.9
1995	61.8	50.4	17.6	365.9	38.6
1996	58.8	49.0	11.0	267.0	35.8
School energy (s_A)					
1992	18 313	7684	537	163 248	24 185
1993	19 865	9268	304	225 530	28 652
1995	15 343	6214	217	366 875	28 549
1996	12 663	4361	290	262 423	23 640
School internal density (s_A/*area*)					
1992	423	186	1	3216	599
1993	1098	399	7	27 322	2364
1995	482	203	0	15 150	1177
1996	426	162	1	18 223	946

inter-annual differences (Kruskal–Wallis test $H = 19.29$, $P < 0.001$), as well as differences in pairs between each of the years analysed (Kolmogorov–Smirnov test, $P < 0.001$).

4. Discussion

In general, it could be concluded that schools recorded during the 1992 survey differed markedly from those recorded during the other three surveys, in terms of all three variable types. The 1992 survey was mainly characterised by a small number of large schools restricted to a small area, distant from the coast, at greater depths and having an intermediate internal density with respect to the other years under study. On the other hand, the 1993 survey showed the exact opposite of 1992. It was characterised by a greater number of schools, which occupied a larger geographic area, very close to the coast and closer to the surface. These schools also had a higher internal density than the other years. Although the years 1995 and 1996 had different numbers of schools, they were quite similar in terms of size, distance from the coast, depth and density, while school variable values ranged midway between those of 1992 and 1993.

The inter-annual variability observed in school energy may be largely attributed to a change in the proportion of schools having a low or high level of energy. Fig. 4 shows a gradual yearly increase in the proportion of schools with low energy (below 10 000s_A) as compared to the other energy classes under consideration, and a slight increase in schools of the highest energy class (over 100 000s_A) in 1993 only.

Although all the schools detected were analysed without differentiating between species, the pelagic trawls carried out during these surveys give us an indication of the species composition in the area studied. During the first three years (1992, 1993 and 1995) 90% of the fish were attributed to sardine and/or anchovy, while the remaining 10% was made up by other pelagic species (sardinella, horse mackerel, mackerel and bogue). In 1996, the percentage of these other pelagic species had jumped to 25%, with the sardinella alone accounting for 10% (unpublished data). Therefore, the species composition of the area during the study period is characterised by the dominance of sardine and anchovy during the first three years, and by the emergence of a considerable number of other pelagic species from 1996 onwards.

In 1992, the abundance of the 0 and 1 sardine age group was high as a result of good recruitment in 1991 and 1992 (Abad et al., 1998a). Good anchovy recruitment was also measured in 1992, resulting in a strong anchovy 0-year-old age group (Abad et al., 1998b). Since 1993, however, the recruitment of these two species declined substantially. In fact, 1993 was particularly noteworthy for the low percentage of juveniles (age 0), and for the increase in the ratio of group-1 anchovy specimens, as compared to sardine (Abad et al., 1998a,b).

Hence, variability observed in the school parameters studied would not appear to be due to the composition of the species in the area each year, but rather to the age, and therefore, to the size of the species. The existence of a higher ratio of juveniles to adults, regardless of the species (sardine, anchovy, sardinella or others) would seem to be the explanation for the different aggregations seen in the different years, as well as the reason for their variability. That leads to the difficulty in differentiating species by its school's characteristics or echo-trace.

The number of schools found annually in the area studied did not correlate with the annual biomass (Abad et al., 1998a,b) of the principal pelagic species assessed, since although the biomass as a whole decreased over the course of these four years, the number of schools fluctuated from year to year (Fig. 5). In the studied area, sardine biomass has diminished gradually and that of the anchovy has fluctuated from year to year due probably to high fishing mortality, this

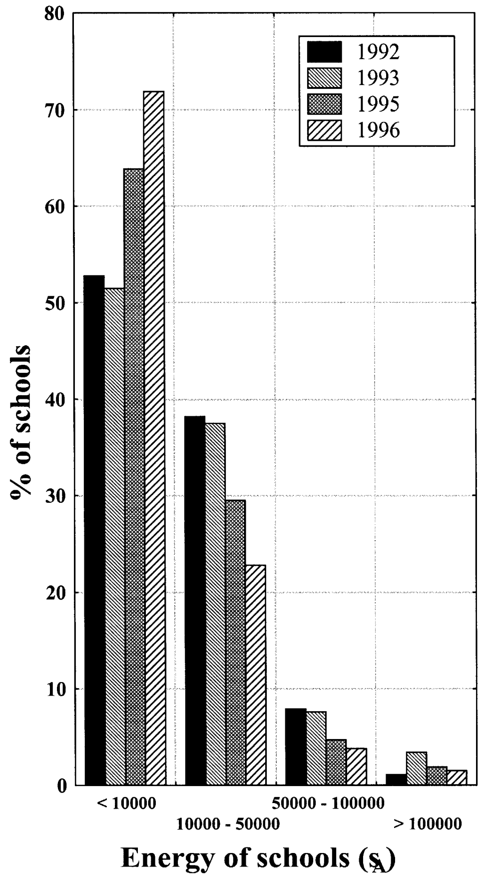

Fig. 4. Percentage of schools belonging to different intervals of energy (s_A), per year.

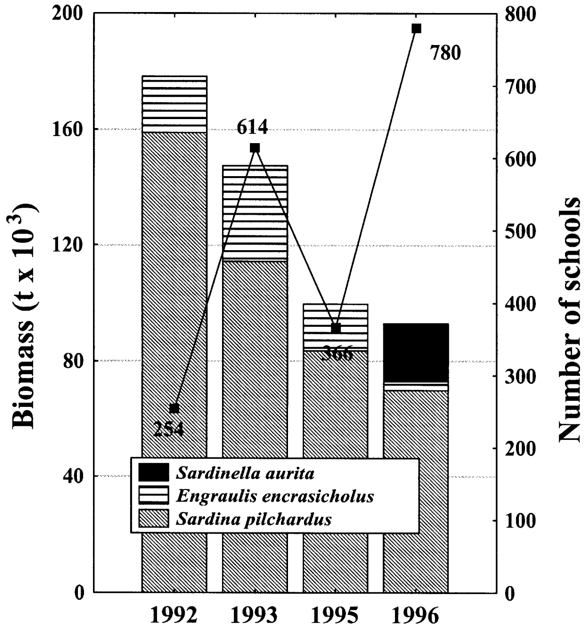

Fig. 5. Biomass (tonnes) of pelagic species assessed every year, and number of schools.

being the target species of the purse seine fleet. In 1996, other pelagic species started to be observed occupying the trophic niche vacated by the decreasing sardine and anchovy populations. Therefore, the number of schools is not a measure of the relative abundance of the different pelagic species, which depends directly on the size and density of the schools; other studies in different geographic areas have reported similar results (Petitgas and Levenez, 1996; Auckland and Reid, 1998; Petitgas et al., 2001).

It was also observed that the mean annual energy of the schools decreased in the study area as a whole over the 4-year period (Table 1). Backscattering energy is a function of both number of individuals and their size. Over the course of these four years, there has been a gradual decline in sardine and anchovy recruitment (unpublished data), which means a decrease in the relative number of small sized individuals (age group 0), and consequently, an increase in the mean annual size. Therefore, it would appear that the decrease in mean energy seen here is due to a decrease in the total number of individuals in the area surveyed, rather than to a decrease in the mean size of these specimens.

The Ebro Delta is the main area where schools were detected and this is due to its special oceanographic characteristics. The input of the Ebro river, as well as the "upwelling" associated with the coastal winds (Font, 1990; Millot, 1990; Salat, 1996) gives rise to high concentrations of nutrients. This phenomenon is strengthened by the existence of permanent "upwelling" originating from the intrusion of water from the open sea towards the shelf in the mouth of the Ebro (Font et al., 1990). The combination of the two factors makes the Ebro Delta a highly productive area in terms of phytoplankton and zooplankton, and hence of great trophic importance to the major pelagic species. Moreover, the proximity of freshwater runoff flowing into the Mediterranean Sea would appear to favour the spawning of the sardine and the anchovy.

Finally, the schools of small pelagic species found in this area of the Spanish Mediterranean Sea exhibit diurnal aggregative behaviour, forming schools during the daylight hours, while the individual fish disperse at night. This clearly defined aggregative behaviour was previously described in the Mediterranean, for the Adriatic Sea (Azzali et al., 1981, 1985), in a study reporting the same pattern of school formation during the daylight hours and which is a classic pattern in these species (Shaw, 1961; John, 1964; Blaxter and Hunter, 1982).

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