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The structure and spatial distribution of pelagic fish schools in multispecies clusters: an acoustic study

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Two acoustic surveys were carried out in the Bay of Biscay, in 1993 and 1994, to study the distribution and abundance of pelagic stocks. Acoustic data were systematically stored using the INES/MOVIES acquisition and processing system along isobath perpendicular transects, from 25 m to 200 m bottom depth. Species identifications were obtained from midwater trawl catches. From the acoustic data, sections of cruise track in the vicinity of the trawl catches were selected for analysis. Three species, anchovy (*Engraulis encrasicolus* L.), sprat (*Sprattus sprattus* L.), and horse mackerel (*Trachurus* sp.) were investigated. The objectives of this study were to analyse the echo traces for estimation of species-specific preferences and to examine the influence of species assemblages on the vertical position and shape of the schools. Using MOVIES-B software, 4789 fish schools were detected and isolated. Characteristics investigated were size (height, vertical cross-sectional area), elongation (length/height), back-scattered energy (density), and vertical distribution (bottom depth, school altitude). Comparative analysis of the vertical distribution of echo traces and catch compositions revealed some species-specific preferences. Horse mackerel were found close to the bottom and anchovy at a mean of 16 m above the bottom. No variation in vertical distribution was detected where sprats were mixed with anchovies. In the presence of horse mackerel in the bottom layer, anchovy appeared to be displaced upwards. A modification of the shape of schools was also detected when sprats were mixed with anchovies. In anchovy–horse mackerel mixtures, a suggested modification of behaviour could explain the observed decrease in the density of anchovy schools.

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Introduction

Spatial heterogeneity of the abiotic environment is responsible for the concentration of fish in the most favourable areas, the extent of which vary from the micro-habitat to the regional scale. The use of space by a fish is defined by its pattern of movement, which may be related to the presence of other fish, especially conspecifics, as well as to the physical environment. Individual reaction to the presence of other fish will result in the formation of schools or in some form of territoriality. Several functions of schooling have been reviewed by Pitcher (1993). An individual fish lives within a complex web of interactions. Coexistence of species may depend on form and behaviour being complementary. Weaker interactions may lead to a partial change of spatial pattern with species moving away from their optimal range of environmental conditions. This segregation depends not only on fish size but also on phenotypic and behavioural characteristics. Interspecific competition may cause resource partitioning but this can also result from other processes, including predator avoidance (Wooton, 1990 for a review).

Taking advantage of the development of acoustics, fish behaviour has been more and more studied in the field and in laboratory since the early 1950s. Because of the influence of school behaviour on acoustic biomass estimates, several studies were carried out on school distribution (Scalabrin and Massé, 1993; Marchal and Petitgas, 1994) and behaviour in relation to different stimuli, such as trawl, vessel, or predators (Diner and Massé, 1987; Fréon *et al.*, 1992; Misund and Aglen, 1992). Because of the difficulty of splitting the biomass into species, the classification of fish schools or acoustic

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populations is a recurrent worry among scientists (Gerlotto and Marchal, 1987; Rose and Leggett, 1988; Swartzman *et al.*, 1994).

In the present study the species-specific fine-scale vertical distribution, recorded by acoustics, is analysed in order to estimate species-specific preferences and then to examine the influence of species assemblages on the vertical position and shape of the schools.

Material and methods

The observations were made on board RV ''Thalassa'', during two acoustic surveys, ERAG93 and ERAG94 carried out in the south-east Bay of Biscay (Fig. 1) from 4 June to 23 June 1993 and from 15 May to 9 June 1994. The vessel was equipped with a single beam echo-sounder OSSIAN 1500 (38 kHz) with a TVG amplification of 20 log R. The pulse duration was 1 ms with a 8° beam angle. Acoustic data were collected using the INES/MOVIES (Diner *et al.*, 1989) acquisition and processing system.

The area was sampled by isobath-perpendicular transects, from 25 to 200 m bottom depth at a speed of about 9 knots. Two different pelagic trawls were used to identify echo traces: a large mesh trawl (stretched mesh length 16 m) with a vertical opening of 20 m and a small mesh trawl (stretched mesh length 800 mm) with a vertical opening of 12 m. Both of them were fitted with a 10 mm codend. Two types of hauls were adopted: in one the vertical position of the trawl was varied in order to sample the majority of the detected echo traces, in the other two successive hauls sampling different vertical layers were made. All fishing operations considered in this study were done during day-time. The duration was variable, according to the stability of the echo trace distribution but generally did not exceed 1 h.

Catch composition was considered to be representative of species assemblage in the area. Of 52 hauls, 26 were selected for the present study (Fig. 1), according to the following criteria: (i) presence of one species comprising at least 85% of the catch by weight, with other species representing individually less than 5% of the total catch, and (ii) two-species assemblages in which each made up at least 20% and both of them represented at least 90% of the total catch.

Using the previous criteria, three species were considered: anchovy, sprat, and horse mackerel. Acoustic data from sections of transect surveyed in the neighbourhood of the selected hauls were analysed. Only day-time survey data within 1 nautical mile of the median fishing position were utilized. In all, 200 nautical miles of cruise track were selected, in which 4789 schools were analysed with MOVIES-B software (Weill *et al.*, 1993) in order to describe aggregations (Table 1).

Four different types of aggregation were observed: 468 schools were attributed to anchovy (based on 4 hauls), 1672 schools to horse mackerel (4 hauls), 1064 schools to a mixture of anchovy and sprat (8 hauls), and 1585 schools to a mixture of anchovy and horse mackerel (10 hauls). For each school, only six descriptors were considered in this study from the 32 parameters given by MOVIES-B (Scalabrin and Massé, 1993): bottom depth, height, and area of the school (vertical cross-sectional area), elongation coefficient (length/height), altitude of the school (distance from the bottom to the presumed centre of gravity of the school), and a density value (backscattered energy/area) defining an index of packing intensity.

For each species (or species mixture) schools were characterized according to the previous descriptors and classified into four strata according to their bathymetric distribution (depth less than 60 m; from 60 m to 90 m; from 90 m to 120 m and >120 m). Estimates of the average and standard deviation are presented in Table 1. For each type of school and depth stratum the frequency distribution of the distance between the centre of gravity and the bottom was computed by 2 m layers.

Results

The observed vertical distributions of the school's altitude for each depth stratum and for each category of school are presented in Figure 2. The vertical lines delimit the layers sampled by the trawl during each haul. The pie charts above the lines represent the proportion of the species in the total catch.

When anchovy was the dominant species in an area (Fig. 2a) the vertical distribution of the schools appears fairly stable regardless of bottom depth (at about 16 m above the bottom). These schools had a mean area of 24.3 m^2 (Table 1). A smaller peak at 30 m above the bottom was mainly due to the presence of some very large schools (mean area 142.5 m^2) recorded at a height of greater than 25 m above the bottom. When horse mackerel was the dominant species (Fig. 2b) the majority of the schools were observed close to the bottom and the spread of the distribution increased with the depth. A more skewed vertical distribution of schools appeared when anchovy was mixed with sprat (Fig. 2c) with the majority of the individuals found in layers close to the bottom. No evidence of vertical separation of the species was observed, as indicated by the pie charts associated with each haul (vertical lines). In the case of anchovy–horse mackerel assemblages (Fig. 2d), a vertical bimodal distribution was evident. Anchovy was mainly distributed in the upper layer (mode between 25 and 30 m from the bottom), while horse mackerel remained close to the bottom. Compared with the vertical distribution of pure anchovy (when it was alone in the area), there was an upward movement of 10 m. As in the case of horse mackerel alone, the vertical extent of the distribution increased with the bottom depth.

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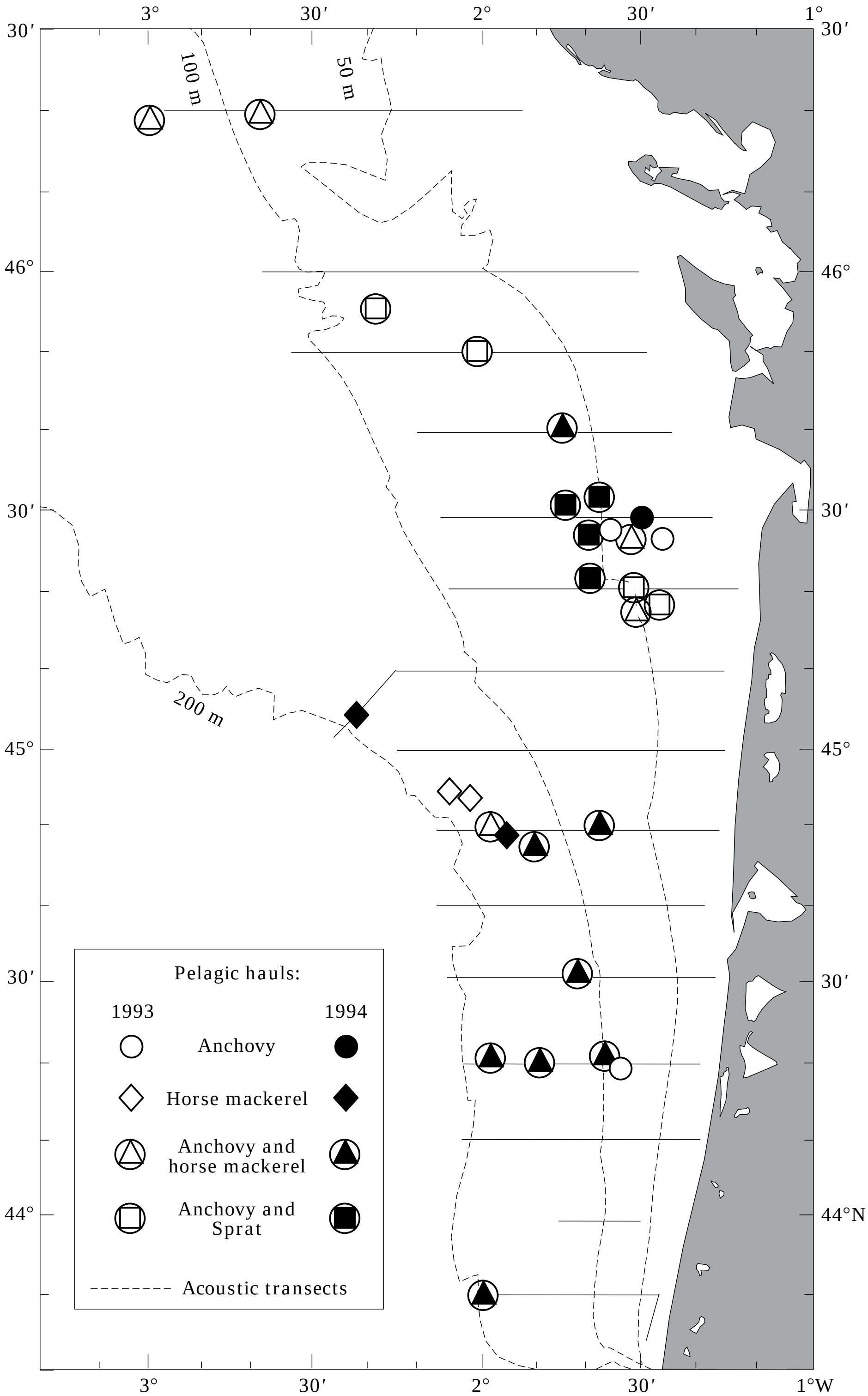

Figure 1. Area sampled during ERAG93 and ERAG94. Selected fishing operations are represented in white (for ERAG93) and black (for ERAG94) with symbols according to the dominant species present. Lines show the transect grid on which surveyed tracks were selected for the present study.

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Table 1. Number of schools observed by altitude strata and estimates of the average and standard deviation of school descriptors: HMAX is the maximum height, AREA is the vertical cross area, and ELONG is the ratio height/length to describe the shape of the schools. DENSITY is the ratio energy/area relative to packing intensity.

Species	Anchovy		Horse mackerel	Anchovy and sprat		Anchovy and horse mackerel	
Altitude (m)	<25 m	>25 m	Tot.	<10 m	>10 m	<10 m	>10 m
No. of schools	432	36	1672	538	526	880	705
H_{max} (m)							
Average	2.8	4.6	3.1	3.6	4.3	2.9	3.5
S.D.	1.9	3.8	3.5	2.2	3.6	1.6	3.3
Area (m^2)							
Average	24.3	142.4	40.9	31.5	29.4	39.4	29.7
S.D.	24.3	290.8	106.8	43.7	32.0	44.7	39.3
Elong							
Average	6.5	6.5	8.4	5.6	3.6	8.9	6.1
S.D.	2.9	3.0	5.4	4.4	1.9	5.4	3.6
Density							
Average	21.5	23.8	5.2	23.4	34.9	12.7	8.3
S.D.	24.2	29.6	15.4	36.4	47.9	42.6	11.9

The influence of species composition on the shape of the schools was studied by the analysis of the frequency distributions of their elongation (Fig. 3). In the case of areas where anchovy and horse mackerel were found in close proximity, only anchovy schools, i.e. those in the upper layer (altitude >20 m) were considered. The elongation frequency distribution of anchovy schools remained stable whether the species was alone or in close proximity to horse mackerel. When anchovy was found with sprat, however, the mode of the frequency distribution was between 2 and 3, instead of 6 and 8 found in the previous cases, while the distribution was more skewed, i.e. schools were less horizontally stretched. The Kolmogorov-Smirnov two samples comparison (K-S test) gave a significance level of 0.99 for schools in areas with anchovy alone versus those with anchovy plus horse mackerel, and 0.08 for anchovy alone versus those with anchovy plus sprat. This indicates that the presence of sprat affects the shape of the schools in the case of the anchovy–sprat mixture. In contrast, the presence of horse mackerel affects the vertical distribution of anchovy without modifying the shape of the schools.

Discussion

The comparative analysis of the vertical distribution of echo traces and the catch composition reveals some species-specific preferences. Horse mackerel was found close to the bottom and anchovy above the bottom at a mean altitude of 16 m. The analysis of the altitude frequency distributions shows a rather stable spread for anchovy, whatever the area, while the horse mackerel distribution spread increased in deeper areas. This vertical extension of the occupied layer could be linked with light intensity preferences. Many studies have found evidence of diel vertical migrations but whether or not fish have a day-time vertical distribution linked to an optimum level of illumination is still debated. This vertical extension could also be linked to species-specific hydrological preferences relating to a seasonal thermocline which is well established in this area in late spring at depths varying between 15 and 30 m. Thus, the vertical extent of the cold homogeneous water masses below the thermocline increases with bottom depth.

Several laboratory and field studies show that fish prefer the company of individuals matching in body size (Pitcher, 1993; Ranta *et al.*, 1992). This is generally true for single-species schools, but references to multispecies aggregations are less frequent (Fréon, 1984). In the present study the presence of horse mackerel in the bottom layer seems responsible for the upward displacement of anchovy schools, although the mean size of the horse mackerel (14 cm) is close to the size of anchovy. It is suggested that, as horse mackerel is generally considered an anchovy predator, efficient segregation of the two species is imposed.

No important modification of the vertical distribution was detected in the case of an anchovy–sprat mixture. These species have similar phenotypes and it seems that they have more competitive interactions than predator–prey relationships. In this kind of assemblage the major change concerned the shape of the schools but no natural explanation was found. As neither acoustic nor fishing information let us identify single-species schools, it is suggested that two-species schools could exist in this case. Our results suggest an increase of repulsive forces between anchovy and horse mackerel, while the balance between repulsion and attraction had no significant effect in the case of anchovy–sprat associations.

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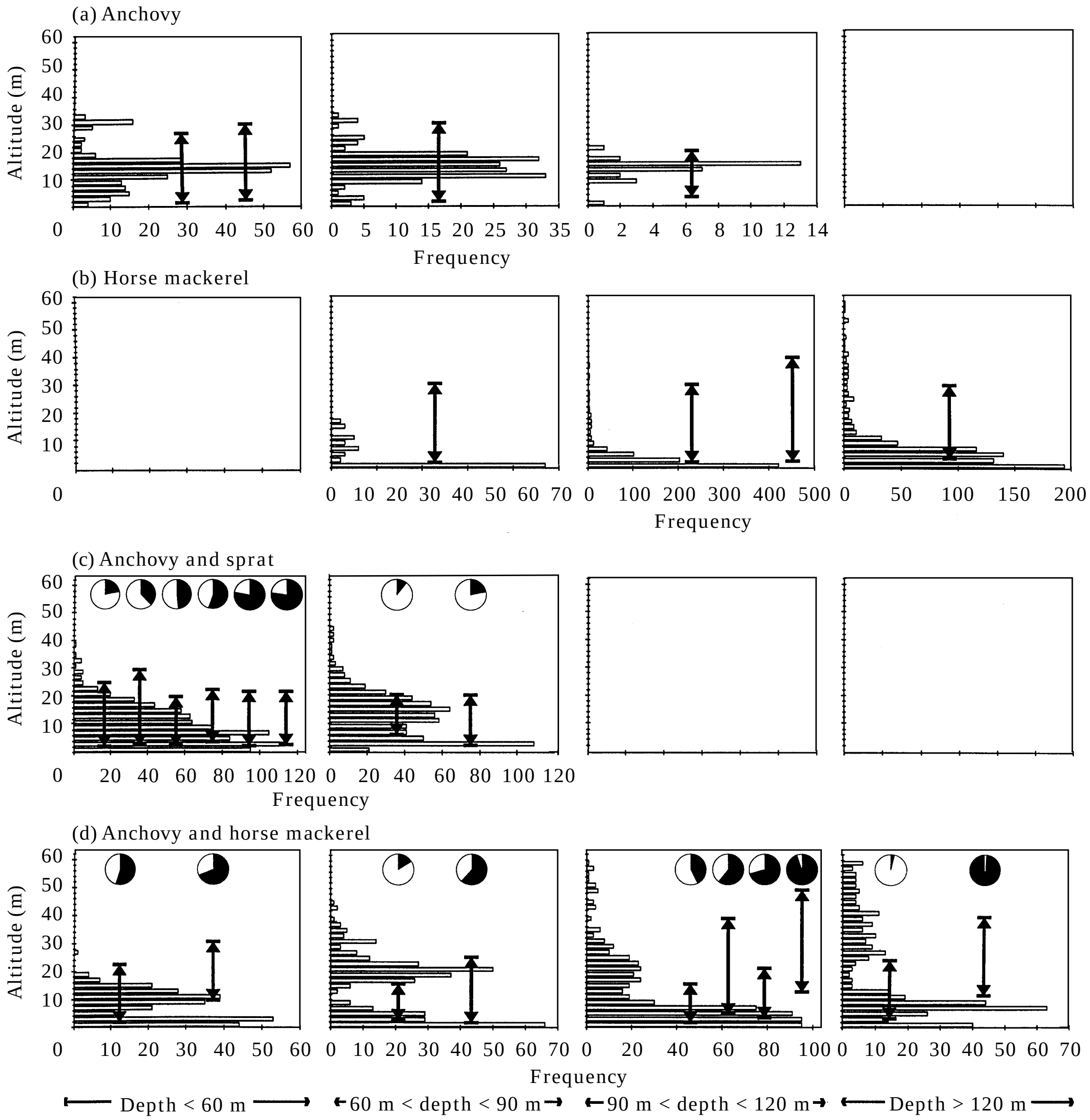

Figure 2. Frequency distribution (number of schools) according to the distance between the school centre of gravity and the sea bottom (altitude) for each species or species assemblage and depth stratum. Vertical lines represent the layer sampled by midwater trawl and the pie charts above indicate the proportion of the species in the total catch (anchovy is always in black and the other species in white).

The density of anchovy schools decreased when horse mackerel was present (from 21.5 to 8.3 in the presence of horse mackerel, Table 1). This is contrary to the hypothesis concerning increased swarming in the presence of predators. Following several studies (Nakken and Olsen, 1977; Foote, 1980) the target-strength of fish decreases considerably with tilt angle, with maximum values obtained in a horizontal position. In the present case, the presence of horse mackerel in the bottom layer could be considered as a disturbance generating an upwards migration of anchovy and an increasing random component in fish movements which could affect the reflected energy.

Both vertical distribution and schooling behaviour appear to be influenced by the species composition of schools of small pelagic fish. The acoustic characteristics of schools were modified in the case of a two-species mixture. The question remains whether or not these changes could affect the results of acoustic biomass estimation.

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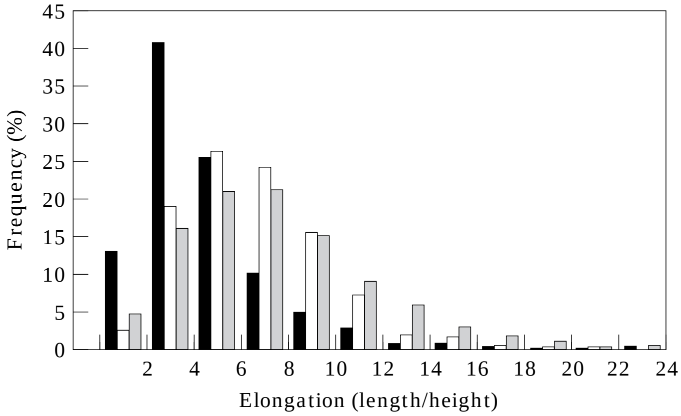

Figure 3. Relative frequency distribution of elongation index (length/height) for schools when anchovy is present alone or combined with sprat or horse mackerel. The higher the coefficients, the more elongated horizontally are the schools. ■ = anchovy–sprat; □ = anchovy; ▨ = anchovy–small horse-mackerel.

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