Marine Ecology. ISSN 0173-9565

ORIGINAL ARTICLE

Distribution and spatial structure of pelagic fish schools in relation to the nature of the seabed in the Sicily Straits (Central Mediterranean)

Marta D'Elia[1], Bernardo Patti [1], Attilio Sulli[2], Giorgio Tranchida[1], Angelo Bonanno[1], Gualtiero Basilone[1], Giovanni Giacalone[1], Ignazio Fontana[1], Simona Genovese[1], Cástor Guisande[3] & Salvatore Mazzola[1]

1 Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Sede di Mazara del Vallo, Mazara del Vallo (TP), Italy
2 Dipartimento di Geologia e Geodesia di Palermo, Palermo, Italy
3 Facultad de Ciencias, Campus Universitario Lagoas-Marcosende, Universidad de Vigo, Vigo, Spain

Keywords
acoustic surveys; bottom and fish backscattering; echo-sounder; fish school; seabed; Sicily Channel.

Correspondence
Bernardo Patti, Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Sede di Mazara del Vallo, via L. Vaccara 61, 91026 Mazara del Vallo (TP), Italy.
E-mail: bernardo.patti@cnr.it

Conflicts of interest
The authors declare no conflicts of interest.

doi:10.1111/j.1439-0485.2009.00328.x

Abstract

Hydroacoustic data collected during two echosurveys carried out in the Sicily Channel in 1998 and 2002 were analysed to investigate the distribution and spatial structure of small pelagic fish species in relation to the sedimentological nature of the sea bottom. The study was carried out on two contiguous areas (labelled ZONE 1 and ZONE 2) of the continental shelf off the southern coast of Sicily, characterised by different dominant texture, 'sand' for ZONE 1 and 'clayey-silt' for ZONE 2. Simultaneous information on small pelagic fish schools and the seabed was obtained using a quantitative echo-sounder (SIMRAD EK500) that measures echoes due to the scattering from both fish schools and the bottom surface. Acoustically determined fish school and seabed data were integrated, respectively, with information on species composition obtained by experimental fishing hauls, and with granulometric information obtained from the analysis of *in situ* sediment samples. The results indicate a general preference of small pelagic fish schools for seabeds of finer granulometry. First, the occurrence of fish schools was higher over the acoustically classified 'soft' seabeds of ZONE 2. Secondly, although ZONE 2 represents <30% of the total length of daytime acoustic tracks analysed in this study, in both surveys the bulk of fish biomass (>60%) was concentrated over 'soft' seabed substrates of ZONE 2. Different species composition and/or behaviour of fish schools in the two areas investigated were postulated in relation to seabed conditions. Specifically, over the hard and soft bottoms of ZONE 2, fish schools were found at lower depths and at shallower bottom depths compared to ZONE 1. Furthermore, over the softer bottoms of ZONE 2, fish schools exhibiting a more 'pelagic' behaviour (*i.e.* detected at a greater distance from the bottom) showed a preference for softer (and finer) seabed substrate conditions. Conversely, fish schools exhibiting a more 'demersal' behaviour (*i.e.* at a smaller distance from the bottom) were mostly found on relatively harder substrates.

Problem

Small pelagic fishes are a significant component of the Mediterranean fisheries and they are also important to the ecosystem as they constitute the main prey of a large number of fish such as tuna, cod and mackerel. In the Mediterranean Sea there are eight main small pelagic species. Only four of them – anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*), round sardinella (*Sardinella aurita*) and sprat (*Sprattus sprattus*) – are considered to be fully pelagic, whereas Atlantic mackerel (*Scomber scomber*), chub mackerel (*Scomber japonicas colias*), bogue (*Boops boops*) and Atlantic horse mackerel (*Trachurus trachurus*) have more or less prolonged biological stages with pelagic behaviour (Alvares *et al.* 2003). Two of these species, the European anchovy and the European sardine, are important fishery resources in the Sicilian Channel, and historically have been exploited by fishermen from the north-western and southern coasts of Sicily.

The pelagic species are social animals that live in mono- or plurispecific schools with a highly patchy distribution (Fréon & Misund 1999). The distribution and the spatial structure of pelagic schools is a complex phenomenon that is controlled by a number of interactive mechanisms and factors (Maravelias 1999; Bahri & Fréon 2000; Soria *et al.* 2003).

Some authors also considered the nature of the seabed to be a possible factor affecting fish spatial distribution (Genin & Boehlert 1985; Dower *et al.* 1992; Maravelias 1999; Maravelias *et al.* 2000; Manik *et al.* 2006a). Specifically, the nature of the seabed was found to modulate the presence and relative abundance of Atlantic herring (*Clupea harengus*) within the northern North Sea, with species clustering in habitats with a depth between approximately 100 and 150 m and a gravel/sand type of seabed, which also carried the highest abundance of zooplankton (Maravelias 1999; Maravelias *et al.* 2000). Manik *et al.* (2006a), on the other hand, using hydroacoustic data collected during an echo-survey carried out during December 2003 in the Indian Ocean, on the southern coast of Jawa Island (Indonesia), generally observed a higher occurrence of fish schools (64 schools of the total of 66 detected) over sandy bottoms. Furthermore, the presence of seamounts may affect the aggregation and movement of small pelagic fishes (Allain *et al.* 2008). The presence of these topographic features on the ocean floor determines the uplifting of isotherms, isopycnals (Genin & Boehlert 1985) and nutrient isolines (Comeau *et al.* 1995). This upward deflection of deeper, more nutrient-rich waters can lead to an increase in primary production if its effects reach up into the euphotic zone, where there is enough light for photosynthesis (Furuya *et al.* 1995; Odate & Furuya 1998). The same effect could be produced by different geological structures such as benches, platforms, relieves or marine terraces (Allain *et al.* 2008).

Some topographic features, such as the degree of land enclosure and size of habitat, were also found to affect the spatial structure of anchovy and sardine schools in the Eastern Mediterranean, suggesting that environmental spatial heterogeneity, attributable to coastal topography, is able to affect the way fish schools become organised into aggregations (Giannulaki *et al.* 2006).

Another important feature of habitat selection related to the seabed is the frequent association of pelagic species with sudden breaks in the bottom depth due to submarine canyons, escarpment areas or deep water basins located close to the shore, as reported by Mais (1977) for the northern anchovies (*Engraulis mordax*) in the California current system.

Habitat selection related to the seabed could also be linked to the daily vertical migration of these species along the water column. For instance, Dias *et al.* (1989) and Zwolinski *et al.* (2007) reported that sardine and pelagic fish schools off Portugal are often observed on the bottom during the night, with schools descending towards the seabed during their expansion at dusk, and remain in close contact with the seabed throughout the night. Although the descent may be linked to the spawning behaviour of the species, with reproduction occurring at dusk close to the seabed (Zwolinski *et al.* 2007), similar patterns have been observed off Portugal outside the spawning season (Dias *et al.* 1989). This pattern of diel vertical migration contrasts with that reported for sardine in the Eastern Mediterranean (Giannoulaki *et al.* 1999) and for the round sardine (*S. aurita*) in Senegal. Nieland (1982) found a large proportion of mud and sediments that had a non-negligible energetic value in the stomach of these sardines (*S. aurita* off Senegal).

For pelagic fish, light above a certain threshold is needed for visual predation (Blaxter & Hunter 1982). For such species, upward migration at dusk has been identified as a strategy for increasing feeding opportunities at twilight (Blaxter & Holliday 1963; Cardinale *et al.* 2003). In contrast, filter-feeding clupeids can feed on abundant or small prey even in darkness (Batty *et al.* 1986). The presence of schools close to the bottom may be due to the presence of sufficient food or to processes unrelated to feeding, such as the use of the shelf for orientation during migration (Kim *et al.* 1993).

In the present study the geographical distribution and the spatial structure of pelagic fish schools off the southern coast of Sicily (Central Mediterranean) detected by image analysis algorithms applied to hydroacoustic data were examined to investigate their association with the nature of the seabed. This study is of primary interest for stock assessment and management aims because it could allow identification of favourable environmental conditions or micro-habitats at small time scales for the pelagic species in the Sicilian Channel.

Material and Methods

Study site description

This study is mainly based on acoustic information gathered in the Sicilian Channel over the two sectors labelled in Fig. 1 as 'ZONE 1' (north-western sector, over the

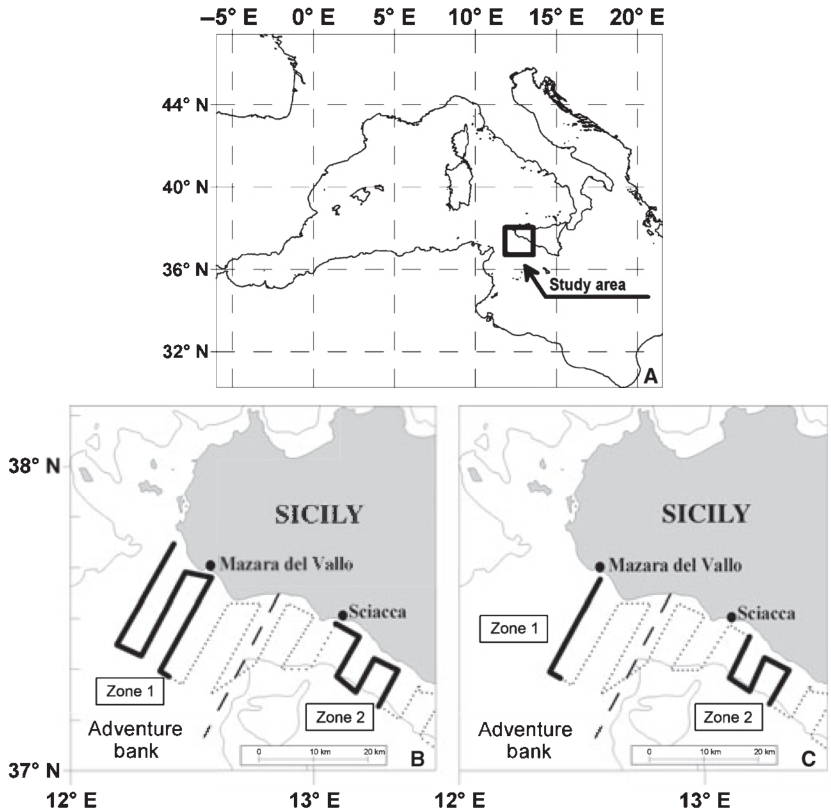

Fig. 1. Location of the study area (A), showing the echosurvey tracks (dotted line) and day-time transects (superimposed thick line) in 1998 (B) and in 2002 (C: only the survey tracks performed in the day time also in 1998, selected for comparative purposes, are displayed). The dashed line separates ZONE 1 from ZONE 2.

Adventure Bank; total length of acoustic transects: 83 nautical miles) and 'ZONE 2' (south-eastern sector, continental shelf off the central part of the Southern Sicilian coast; total length of acoustic transects: 34 nautical miles). These two sectors are characterised by different dominant seabed conditions, harder (and coarser) in ZONE 1 and softer (and finer) in ZONE 2.

Fish schools

Data on the distribution and the spatial structure of pelagic schools were collected during two hydroacoustic surveys carried out on the continental shelf off the southern coast of Sicily aboard the N/O *Salvatore lo Bianco* in June 1998 and the N/O *G. Dallaporta* in July 2002.

For the aims of the present study, only day-time acoustic transects were used, as during night time fish schools tend to disperse in the water column. Acoustic data were acquired by means of the scientific echo-sounder Simrad EK-500. For each transect, the volume backscattering coefficient (S_v, dB per cubic metre ref. to 1 μPa at 1 m) along the water column at 38 kHz was measured, with a vertical resolution of 1 m and a horizontal resolution in the range 1–10 m (depending on the bottom depth).

Fish schools were identified from echograms using an adapted version of the algorithm introduced by Swartzman *et al.* (1994, 1999). First, raw data were imported in ECHOVIEW v.3 (Sonar Data) post-processing software for the preliminary display and filtering of echograms and converted, using the same software, into ASCII format for the purposes of subsequent analysis. Only pixels of the echograms above the seabed and below the depth of 8.5 m (to remove portions of the echograms affected by air bubbles) were considered. Secondly, image analysis tools (morphological filters) were applied to echograms (Haralick & Shapiro 1992) with the aim of detecting and delimiting objects, in an intensity range for backscattering reflecting the target species, made by contiguous pixels (*i.e.* fish schools) of sufficient backscatter to distinguish them from background noise without smoothing their shape. MATLAB v.6 (The Mathworks) routines were used for this purpose.

Specifically, echograms at 38 kHz were first filtered to select pixels in the backscatter range (−58, −36 dB), setting all pixels outside this range to the background level. Then a morphological filter, created by the application of a closing operator followed by an opening operator with a 2×2 pixel binary structuring element (*i.e.* two pixels on the horizontal axis and two pixels on the vertical axis), was applied to the image. Subsequently, the binary version of the resulting echogram (having '0' values for the background and '1' for pixels included in the analysis) was multiplied by the original echogram at 38 kHz. The final echogram was therefore characterised by the backscattering levels of the original echogram for all identified fish schools and the background level (−100 dB) for all the other pixels. Fish schools were then detected by means of a connected component algorithm, and for each detected school, parameters relative to position (*Depth of the school, Distance from bottom*), size (*Height, Length, Elongation, Area*), energy (*NASC*, nautical acoustic scattering coefficient) and density (*NASC/Area*) were estimated (Fig. 2). A minimum *Area* (4 m^2) threshold was adopted to determine whether a potential acoustical patch was considered a fish school.

Specifically, the following energetic, morphological and positioning descriptors were estimated for each detected fish school:

1 NASC: this value is related to the total biomass of the school, $m^2 \cdot nmi^{-2}$ (nmi = nautical mile; 1 nmi = 1852 m);
2 NASC/Area: this value gives an indication on the average density of the school (Muiño *et al.* 2003); units: nmi^{-2};
3 Length: maximum length of the school, m;
4 Height: maximum height of the school, m (measured as the distance between the uppermost limit and the lowest limit of the school);
5 Elongation: ratio length and height of the school, m;
6 Area: surface of the projected area of the school over the vertical plane, m^2;
7 Depth of the school: school position in the water column with reference to sea surface, m (measured in the centre of gravity of the school);
8 Distance from the bottom: minimum height of the school, m (measured as the distance between the bottom and the lower limit of the school).

Finally, fish school data were integrated with information on species collected with experimental biological hauls carried out during the echosurveys using a pelagic trawl net.

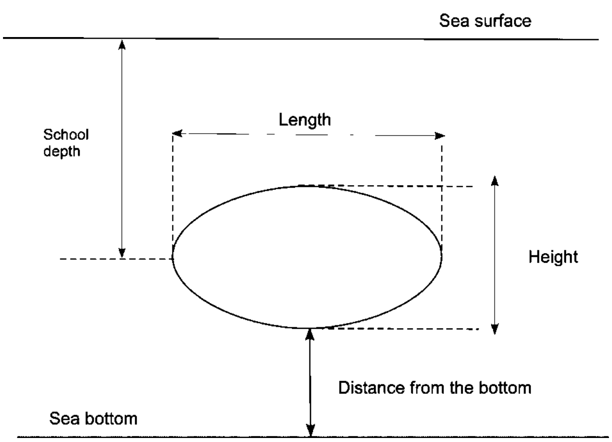

Fig. 2. Example of measured descriptors, giving the position and the geometry of the fish schools.

Seabed data

Information about the nature of the seabed along the acoustic transects was provided using a SIMRAD EK 500 split-beam echo-sounder, originally developed for fisheries surveys. A direct relationship is expected to exist between the mean diameter of the seabed material and the bottom surface (and volume; see Manik *et al.* 2006b) backscattering coefficient: the larger the grain size, the stronger the bottom backscattering strength.

The reason for this is related to the bulk density of the sediments, which in turn is determined principally by porosity. The higher porosity of silt and clay compared to sand accounts for the lower bulk density of 'soft' seabed substrate types compared to 'hard' substrates, so determining the acoustic impedance of the sediment (Nolle *et al.* 1963; Hamilton & Richard 1982; Richardson 1997); the higher the sediment density, the higher the impedance, and the greater the scattering strength.

For each transect the S_V volume backscattering values of the seabed line (referred to as S_{VB}, or bottom S_V, measured in dB per cubic metre ref. to 1 μPa at 1 m) were extracted by means of ECHOVIEW v.3 software. Then a moving average to 50 terms (= acoustic pings), corresponding to about 200–250 m, was calculated to reduce variability in the S_{VB} values. The median value of these averaged S_{VB} data (−33.4 dB) was used to classify the bottom type (0 for S_{VB} values < median value, identifying 'soft' seabed areas, and 1 for S_{VB} > median value, identifying 'hard' seabed areas).

Sediment samples, collected by a grab and box-corer (sample taken at the surface of the seabed) in proximity with the acoustically prospected transects, were also analysed to obtain information on the nature of the bottom type of the two investigated zones in terms of average particle size.

The analysis of the particle size of sediment samples required a phase of sample pre-treatment (digestion with hydrogen peroxide, washing, separation of particles with a diameter lower than 500 μm and drying) and subsequent analysis by a laser diffraction instrument (Fritsch model Analysette 22). Analysis of particle size distribution was conducted using the Wentworth scale, and classification into materials was based on Shepard's method (Shepard 1954).

Results

Fish school data

The analysis of data from 1998 showed that fish schools had a preference for ZONE 2 compared to ZONE 1. Fish schools were more frequent in ZONE 2 (Table 1; the occurrence of fish schools in ZONE 2, 131/294 = 0.45

Table 1. ZONE 1 and 2 features ('N' indicates the number of detected fish schools) and mean values of fish school descriptors by ZONE. Only schools with a bottom depth <200 m are considered. For each descriptor, standard errors are also given within brackets below the average values.

	zone features			fish school descriptors							
ZONE	track length (nmi)	schools·nmi^{-1}	bottom depth (m)	distance from bottom (m)	area (m^2)	length (m)	height (m)	elongation (length/height)	school depth (m)	NASC (m^2·nmi^{-2})	NASC/area (nmi^{-2})
1	83	1.96	80.6	13.7	71.3	17.1	3.97	4.80	64.9	3222	88.2
(N = *163*)	–	–	*(3.2)*	*(1.5)*	*(9.5)*	*(1.1)*	*(0.3)*	*(0.23)*	*(3.2)*	*(589)*	*(20.9)*
2	34	3.85	66.3	23.9	67.7	17.6	3.91	5.07	40.4	5366	122.2
(N = *131*)	–	–	*(3.1)*	*(3.6)*	*(9.5)*	*(1.3)*	*(0.3)*	*(0.27)*	*(1.8)*	*(687)*	*(15.3)*

was significantly higher than the proportion of survey tracks in ZONE 2, 34/117 = 0.29; normal test, Z = 5.9, P < 0.001) compared to ZONE 1, and despite the shorter transect length (34 *versus* 83 nmi), their biomass represented up to 57.2% of the total. On average, morphological descriptors of the analysed fish schools (with bottom depth <200 m) did not show significant differences between the two zones (ANOVA; P > 0.37). Conversely, significant differences were found in positioning (ANOVA; P < 0.01) and energetic (NASC, ANOVA, $F_{1,292} = 5.7$; P = 0.02) descriptors. Specifically, fish schools detected in ZONE 2 had a greater energy and were found at a greater average distance from the sea bottom than schools in ZONE 1, whereas the greater average school depth in ZONE 1 appears to reflect its higher average bottom depth (Table 1). In fact, all school descriptors, with the exceptions of Area and Height, were significantly (and positively) correlated with bottom depth (ANCOVA; P < 0.001).

A similar pattern was found when analysing schools with a centre of mass in the lower half of the water column (schools with ratio between fish school depth and bottom depth >50%). This selection accounted for most of the total fish biomass, including 247 of the total 294 detected fish schools, but removing shallower and less dense aggregations, mostly related to schools in formation or dispersion, which greatly affected the average distance from the bottom of detected schools in the two zones (see Table 2). Hydroacoustic data collected during the 2002 survey were analysed and compared to the 1998 data only in relation to bottom substrate conditions (see below).

Seabed data

The results of the acoustic-based bottom type classification are displayed in Fig. 3, together with information obtained from the analysis of sediment samples collected over the study area. The acoustic classification demonstrates the differences in terms of bottom types between the two zones along the investigated transects. Although the average bottom depth of the prospected transects is higher in ZONE 1, this area (in particular the western sector over the Adventure Bank) is dominated by substrates with greater scattering strength, indicating relatively 'harder' (and coarser) bottom types. In contrast, in ZONE 2 the 'hard' substrate is confined to the shallower inter-transect regions, with the bulk of the seabed deeper than 50 m classified as 'soft' bottom.

The granulometric analysis of sediment samples is consistent with the results of the acoustic classification of the seabed. Although the sediment sample sites were available

Table 2. ZONE 1 and 2 features ('N' indicates the number of detected fish schools) and mean values of fish school descriptors by ZONE. Only schools with a bottom depth <200 m and a ratio between fish school depth and bottom depth >50% are considered. For each descriptor, standard errors are also given within brackets below the average values.

	zone features			fish school descriptors							
ZONE	track length (nmi)	schools·nmi^{-1}	bottom depth (m)	distance from bottom (m)	area (m^2)	length (m)	height (m)	elongation (length/height)	school depth (m)	NASC (m^2·nmi^{-2})	NASC/area (nmi^{-2})
1	83	1.61	78.3	5.51	74.7	16.1	4.24	4.2	70.7	3843	104.7
(N = *134*)	–	–	*(3.7)*	*(0.6)*	*(11)*	*(1.2)*	*(0.3)*	*(0.2)*	*(3.7)*	*(705)*	*(25.3)*
2	34	3.32	55	8.32	68.3	16.5	4.08	4.6	44.7	6165	139.4
(N = *113*)	–	–	*(1.9)*	*(0.7)*	*(11)*	*(1.2)*	*(0.4)*	*(0.2)*	*(1.7)*	*(770)*	*(17.2)*

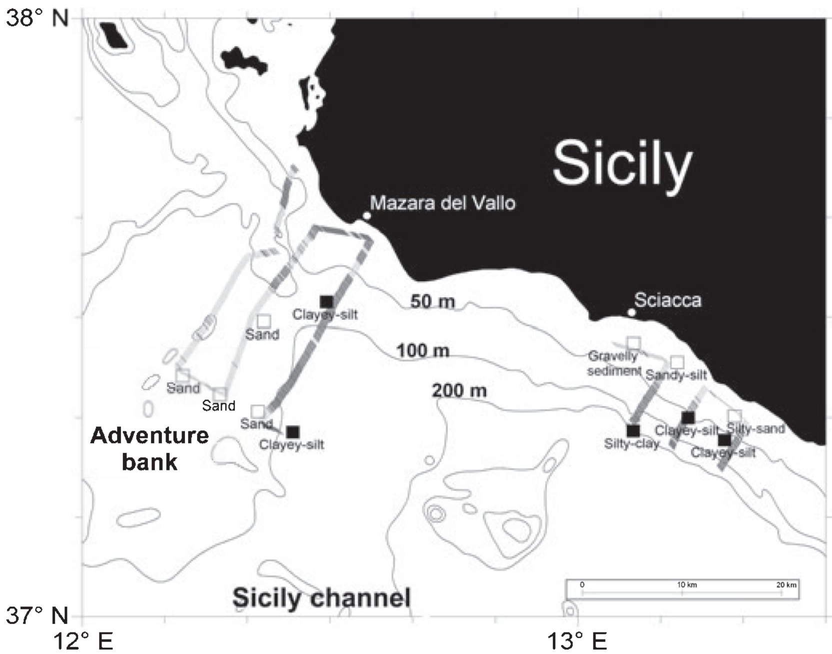

Fig. 3. Acoustic classification of the seabed (1998 day time data), based on bottom S_{VB} values recorded during the day time transects in 1998, binned and averaged every 0.1 nmi. 'Hard' seabeds are displayed in light grey ($S_{VB} \geq$ median value), and 'Soft' seabeds are displayed in dark grey ($S_{VB} <$ median value). The sediment sample sites are also shown, with white squares representing samples with a median particle size ≥8 μm and black squares those with a median particle size <8 μm. Shepard's sediment classification labels are also given under the symbols.

only in proximity to the acoustically prospected transects (within a distance of mostly <1 nmi), it is worth noting that the use of a threshold value of 8 μm for the median particle size of the analysed sediment samples permitted us to separate finer (and softer) substrate locations (classified as clayey-silt and silt-clay), corresponding at the nearest position along the acoustic transect to S_{VB} values lower than the global median value, from coarser (and harder) sediment sites (facies: silty-sand, sandy-silt, sand and gravelly sediment) matching with higher S_{VB} values.

Combination of fish school and seabed data

The spatial structure and distribution of fish schools detected over the continental shelf (bottom depth <200 m) and the centre of mass in the lower half of the water column were linked to the type of seabed.

In terms of morphological school descriptors, in ZONE 1 the average elongation, height and area of fish schools observed during the 1998 survey tended to be positively associated with higher sea bottom S_{VB} values, which were directly proportional to the mean granulometric dimension of the seabed sediment (*i.e.* harder bottom), but this association reverted in ZONE 2 (Fig. 4). However, no significant zone or substrate type effect was found (ANCOVA; $P > 0.05$). School area, length, height ($P < 0.05$), and depth ($F_{1,239} = 321.3$; $P < 0.001$) were positively correlated with bottom depth. Similar patterns, though less pronounced, were also observed during the 2002 survey.

The occurrence of fish schools over the whole study area during the 1998 survey was significantly higher on relatively 'softer' grounds (167/247 = 0.68; normal test, $Z = 5.5$; $P < 0.001$). The preference of fish schools for seabeds with finer granulometry was also observed when considering the two investigated areas separately, as the proportion of schools detected over acoustically 'softer' grounds in both ZONE 1 and ZONE 2 (respectively, 89/134 = 0.66 and 78/113 = 0.69) was significantly higher (normal tests, $Z = 4.0$ and $Z = 3.4$; $P < 0.001$) than the fraction detected over acoustically classified 'soft' seabed in the corresponding zones (respectively, 49% and 53%).

Comparison of the distribution patterns of detected fish schools on 'hard' and 'soft' seabed substrates between the two echosurveys considered in the present study, carried out using only data from day-time transects (Fig. 1B), demonstrated a certain stability over time. In fact, even though fish abundance was considerably lower in the 2002 survey compared to 1998, in both years the occurrence of fish schools over 'soft' and 'hard' seabeds of ZONE 1 was not significantly different. Conversely, in ZONE 2, representing just 29% of the total length of the analysed day-time acoustic tracks (about 53 nmi) but accounting for 57% of seabeds classified as 'soft', fish schools were significantly more frequent (76% in 1998 and 88% in 2002) over bottoms with finer granulometry (year 1998: normal test, $Z = 3.8$, $P < 0.001$; year 2002: normal test, $Z = 4.4$; $P < 0.001$) and accounted for the bulk (>60%) of total estimated fish biomass. The analysis of school descriptors for the 1998 survey did not show any significant ZONE or substrate effect (ANCOVA; $P > 0.05$). Again, bottom depth was found to affect

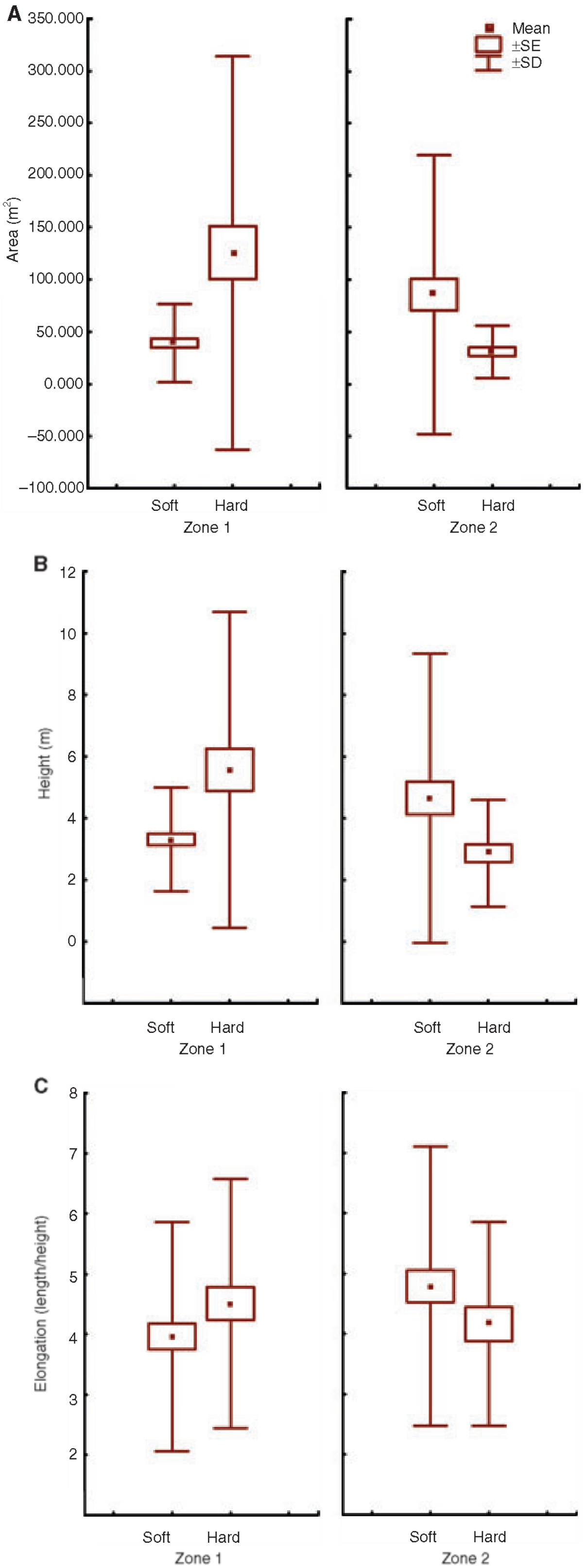

Fig. 4. Box plots of school area (A), height (B) and elongation (C), by type of seabed and by zone, 1998 survey. 'Soft' substrate: S_{VB} < median value; 'Hard' substrate: $S_{VB} \geq$ median value.

school depth (ANCOVA; $F_{1,142} = 140.8$; $P < 0.001$). The same statistical analysis approach (ANCOVA) was used with 2002 data, evidencing the same positive relationship with school area ($F_{1,114} = 4.2$; $P = 0.04$) and school length ($F_{1,114} = 6.8$; $P = 0.01$), whereas with school density the relationship was the inverse ($F_{1,114} = 7.5$; $P < 0.01$). In addition, there was a significant substrate effect on school length ($F_{1,114} = 6.5$; $P = 0.01$) and elongation ($F_{1,114} = 4.9$; $P = 0.03$), with a tendency for longer schools on 'hard' seabeds, and a significant ZONE*Substrate interaction effect on school density ($F_{1,114} = 7.1$; $P < 0.01$).

However, the distribution pattern of fish schools between 'soft' and 'hard' bottoms that was observed during the 1998 survey in ZONE 2 was found to be somewhat linked to the different bathymetry characterising the two types of substrates. Actually, in ZONE 2 the 'hard' sea bottom substrate was restricted to bottom depths shallower than 40–50 m, where low numbers of fish schools were observed.

Using S_{VB} data collected in ZONE 2 only and at depths >50 m, so excluding most of the seabeds previously classified as 'hard', and reclassifying the remaining seabed in relation to the resulting new median of S_{VB} values (−35.71 dB), no significant preference of fish schools for the resulting new 'softer' seabed was found (only 34/60 = 57% of fish schools were detected over seabeds with S_{VB} values lower than the above median threshold). However, even on these deeper seabeds, which were mostly classified as 'soft' when analysed together with ZONE 1 S_{VB} data, it is worth noting that fish schools detected over seabeds that were newly classified as relatively softer tended to be at a greater distance from the bottom, similarly to that previously observed when comparing fish school distribution between ZONE 1 and ZONE 2 during the 1998 survey. In fact, the proportion of fish schools found at a distance from the bottom >5 m was significantly higher on the 'soft' substrate compared to the 'hard' substrate (14/26 = 54% *versus* 9/34 = 23%, one-sided normal test, Yates' correction, $Z = 1.89$; $P = 0.03$) (Fig. 5). These results suggest selection for a relatively coarser substrate by fish schools having a more demersal behaviour, whereas more 'pelagic' fish schools prefer finer substrates. The same pattern for fish schools was observed in the 2002 survey, not only in ZONE 2 but also in ZONE 1.

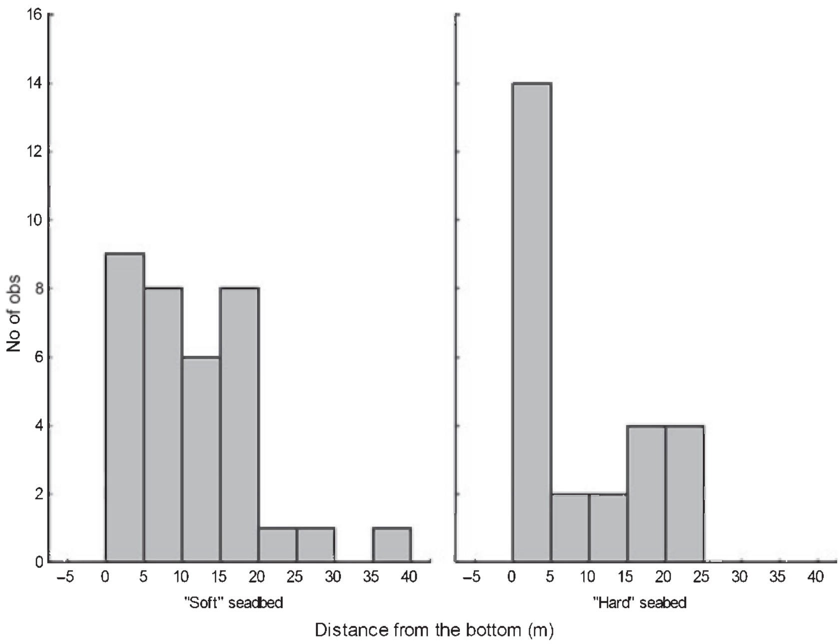

Fig. 5. Fish school distribution in ZONE 2 by seabed type as a function of the distance from the bottom, 1998 survey. The 'Soft' and 'Hard' seabed type refers to ZONE 2 for which grounds with bottom depths >50 m were acoustically reclassified (see text for details).

Discussion

In this study, image analysis algorithms were applied to hydroacoustic data with the aim of characterising the geographical distribution and the spatial structure of fish schools detected during two acoustic surveys carried out in 1998 and 2002 in two separate shelf areas (ZONE 1 and ZONE 2) off the Southern Sicilian coast, and verifying the influence of the seabed substrate, as classified by volume backscattering strength measurements and corroborated by granulometric compositional data, on fish distribution.

The results indicate that fish schools prefer seabeds with a finer granulometry, as in ZONE 2. To our knowledge, this is the first time that such a relationship between fish schools and the nature of the seabed has been established in the Mediterranean Sea, and the first as far as concerns anchovy and sardine, as previous studies were on the Atlantic herring (*Clupea harengus*) in the Northern North Sea (Maravelias 1999; Maravelias *et al.* 2000) or even did not explicitly refer to any particular fish species (Genin & Boehlert 1985; Dower *et al.* 1992; Manik *et al.* 2006a). In addition, the only papers considering the sedimentological nature of the sea bottom (Maravelias 1999; Maravelias *et al.* 2000; Manik *et al.* 2006a) obtained different results compared to those of the present study, as the identified preferred habitats were gravel/sand bottoms

Different species composition and/or fish school behaviour between the two areas investigated is postulated to explain the patterns observed during the 1998 survey. In fact, sardines and anchovies were only found in experimental trawls from ZONE 2, whereas in ZONE 1 horse mackerel was dominant, this being a semi-pelagic fish species whose schools have been reported to occur at small distances from the bottom (Massé *et al.* 1996). However, the patterns observed in the 1998 fish schools in terms of the distance from the bottom were not confirmed by the 2002 data, so inter-survey variability in the distribution pattern of the main pelagic fish species is suggested.

The analysis carried out within ZONE 2 on the relatively 'softer' substrates characterising the seabed at depths >50 m give further insights on the relation between fish school spatial structure and bottom conditions, as there is evidence that the relatively more 'pelagic' (*i.e.* detected at a greater distance from the bottom) fish schools have a preference for softer (*i.e.* finer) seabed substrates. Conversely, fish schools exhibiting a more 'demersal' behaviour (*i.e.* detected at a smaller distance from the bottom) were mostly found on relatively harder (*i.e.* coarser) substrates. So, even relatively small differences in substrate type might provide different optimal day-time habitat conditions for pelagic (or semi-pelagic) fish species.

We consider these results of primary interest not only from the ecological point of view but also to the aims of fisheries management, as the understanding of the effects of environmental factors on fish distribution patterns may represent key information able to improve significantly the quality of scientific advice on exploited fish populations.

Finally, in agreement with previous studies (Misund 1993; Scalabrin & Massé 1993; Ohshimo 1996; Fréon & Misund 1999), data analysis showed that the average fish school length was always greater than average height, suggesting an elongated shape.

Acknowledgements

Hydroacoustic data and sediment samples were collected during oceanographic cruises carried out in the context of the MAGO project (MED98-070), financed by the Commission of the European Communities, Directorate General for Fisheries (DG XIV), and of the ASTAMAR project, financed by the Ministry of Scientific and Technological Research (Italy). The authors would especially like to thank all the people who sailed on the R/V *Urania*, R/V *Salvatore Lo Bianco* and R/V *Dallaporta* for their valuable contribution during the cruises.

References

Allain V., Kerandel J.-A., Andrefouet S., Magron F., Clark M., Kirby D.S., Muller-Karger F.E. (2008) Enhanced seamount location database for the western and central Pacific Ocean: Screening and cross-checking of 20 existing datasets. *Deep Sea Research. Part I, Oceanographic Research Papers*, **55**, 1035–1047.

Alvares F., Cingolani N., Kallianiotis A. (2003) Piccoli pelagici: gestione futura delle risorse condivise in Mediterraneo. *Il Pesce*, **5**, 57–65.

Bahri T., Fréon P. (2000) Spatial structure of coastal pelagic schools descriptors in the Mediterranean Sea. *Fisheries Research*, **48**, 157–166.

Batty R., Blaxter J., Libby D. (1986) Herring (*Clupea harengus*) filter-feeding in the dark. *Marine Biology*, **91**, 371–375.

Blaxter J., Holliday F. (1963) The behaviour and physiology of herring and other clupeids. *Advances in Marine Biology*, **1**, 261–393.

Blaxter J., Hunter J. (1982) The biology of the clupeoid fishes. *Advances in Marine Biology*, **20**, 1–223.

Cardinale M., Casini M., Arrhenius F., Hakkansson N. (2003) Diel spatial distribution and feeding activity of herring *Clupea harengus* and sprat *Sprattus sprattus* in the Baltic Sea. *Aquatic Living Resources*, **16**, 283–292.

Comeau L.A., Vezina A.F., Bourgeois M., Juniper S.K. (1995) Relationship between phytoplankton production and the physical structure of the water column near Cobb Seamount, northeast Pacific. *Deep Sea Research. Part I, Oceanographic Research Papers*, **42**, 993–1005.

Dias C., Soares E., Marques V. (1989) Acoustic abundance estimations of sardine (*Sardina pilchardus*, Walb.) off the Portuguese coast. ICES Document CM 1989/H: 52. 24 pp.

Dower J., Freeland H., Juniper K. (1992) A strong biological response to oceanic flow past Cobb seamount. *Deep Sea Research. Part I, Oceanographic Research Papers*, **39**, 1139–1145.

Fréon P., Misund O.A. (1999) *Dynamics of Pelagic Fish Distribution and Behaviour: Effect on Fisheries and Stock Assessment*. Fishing New Books, Blackwell Science Ltd, Oxford: 348 pp.

Furuya K., Odate T., Taguchi K. (1995) Effect of a seamount on phytoplankton production in the western Pacific Ocean. In: Sakai H., Nozaki Y. (Eds), *Biogeochemical Processes and Ocean Flux in the Western Pacific*. Terra Scientific Publishing Company (TERRAPUB), Tokyo: 255–273.

Genin A., Boehlert G.W. (1985) Dynamics of temperature and chlorophyll structures above a seamount: An oceanic experiment. *Journal of Marine Research*, **43**, 907–924.

Giannoulaki M., Machias A., Tsimenides N. (1999) Ambient luminance and vertical migration of the sardine *Sardina pilchardus*. *Marine Ecology Progress Series*, **178**, 29–38.

Giannulaki M., Machias A., Koutsikopoulos C., Somarakis S. (2006) The effect of coastal topography on the spatial structure of anchovy and sardine. *ICES Journal of Marine Science*, **63**, 650–662.

Hamilton E.L., Richard T.B. (1982) Sound velocity and related properties of marine sediments. *Journal of the Acoustical Society of America*, **72**, 1891–1904.

Haralick R., Shapiro L. (1992) *Computer and Robot Vision*. Vol. **1**. Addison-Wesley, New York.

Kim M.K., Arimoto T., Matsushita Y., Inoue Y. (1993) Migration behaviour of fish schools in set-net fishing grounds. *Bulletin of the Japanese Society of Scientific Fisheries*, **59**, 473–479.

Mais K.F. (1977) Acoustic surveys of northern anchovies in the California current system, 1966–1972. *Rapports et Proces-verbaux des Réunions. Conseil international pour l'exploration scientifique de la mer Mediterranee*, **170**, 287–295.

Manik H.M., Furusawa M., Amakasu K. (2006a) Quantifying sea bottom surface backscattering strength and identifying bottom fish habitat by quantitative echo sounder. *Japanese Journal of Applied Physics, Part 1: Regular Papers & Short Notes*, **45**, 4865–4867.

Manik H.M., Furusawa M., Amakasu K. (2006b) Measurement of the sea bottom surface backscattering strength by quantitative echo sounder. *Fisheries Science*, **72**, 503–512.

Maravelias C.D. (1999) Habitat selection and clustering of a pelagic fish: effect of topography and bathymetry on species dynamics. *Canadian Journal of Fisheries and Aquatic Sciences*, **56**, 437–450.

Maravelias C.D., Reid D.G., Swartzman G. (2000) Seabed substrate, water depth and zooplankton as determinants of the prespawning spatial aggregation of North Atlantic herring. *Marine Ecology Progress Series*, **195**, 249–259.

Massé J., Koutsikopolous C., Patty W. (1996) The structure and spatial distribution of pelagic fish schools in multispecies clusters: an acoustic study. *ICES Journal of Marine Science*, **53**, 155–160.

Misund O. (1993) Dynamics of moving masses: variability in packing density, shape, and size among herring, sprat, and saithe schools. *ICES Journal of Marine Science*, **50**, 145–160.

Muiño R., Carrera P., Iglesias M. (2003) The characterization of sardine (*Sardina pilchardus* Walbaum) schools off the Spanish-Atlantic coast. *ICES Journal of Marine Science*, **60**, 1361–1372.

Nieland H. (1982) The food of *Sardinella aurita* (Val.) and *Sardinella eba* (Val.) off of the coast of Senegal. *Rapports et Proces-verbaux des Réunions. Conseil international pour l'exploration scientifique de la mer Mediterranee*, **180**, 369–373.

Nolle A.W., Hoyer W.A., Mifsud J.F., Runyan W.R., Ward M.B. (1963) Acoustical properties of water filled sands. *Journal of the Acoustical Society of America*, **35**, 1394–1408.

Odate T., Furuya K. (1998) Well-developed subsurface chlorophyll maximum near Komahashi No. 2 Seamount in the summer of 1991. *Deep Sea Research. Part I, Oceanographic Research Papers*, **45**, 1595–1607.

Ohshimo S. (1996) Acoustics estimation of biomass and school character of anchovy *Engraulis japonicus* in the East China Sea and the Yellow Sea. *Fisheries Science*, **62**, 344–349.

Richardson M.D. (1997) *In-situ*, shallow water sediment geoacoustic properties. Proceedings International Conference on Shallow-Water Acoustics, Beijing, China, 21–25 April. China Ocean Press, Beijing: 163–170.

Scalabrin C., Massé J. (1993) Acoustic detection of the spatial and temporal distribution of fish shoals in the Bay of Biscay. *Aquatic Living Resources*, **6**, 269–283.

Shepard F.P. (1954) Nomenclature based on sand-silt-clay ratios. *Journal of Sedimentary Petrology*, **24**, 151–158.

Soria M., Bahri T., Gerlotto F. (2003) Effect of external factors (environment and survey vessel) on fish school characteristics observed by echosounder and multibeam sonar in the Mediterranean Sea. *Aquatic Living Resources*, **16**, 145–157.

Swartzman G.L., Stuetzle W., Kulman K., Wen N. (1994) Modeling the distribution of fish schools in the Bering Sea: Morphological school identification. *Natural Resource Modeling*, **8**, 177–194.

Swartzman G.L., Brodeur R., Napp J., Walsh D., Hewitt R., Demer D., Hunt D., Logerwell E. (1999) Relating fish and plankton acoustically sampled at different frequencies: Data viewing, image analysis and spatial proximity. *Canadian Journal of Fisheries and Aquatic Sciences*, **56**, 188–198.

Zwolinski J., Morais A., Marques V., Stratoudakis Y., Fernandes P.G. (2007) Diel variation in the vertical distribution and schooling behaviour of sardine (*Sardina pilchardus*) off Portugal. *ICES Journal of Marine Science*, **64**, 963–972.