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Narrowband acoustic identification of monospecific fish shoals

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The extraction of highly discriminant features is crucial for successful species identification of fish shoals if backscattered narrowband signals do indeed contain discriminant information. Four different methods of feature extraction are described and applied to the same data, providing new descriptors expected to improve species identification. Echograms, amplitude probability density function (PDFs) and spectral features are used to describe acoustic images of single shoals. Image processing is used to improve signal shoal description, by taking into account the shoal structure and species-related spatial distribution. Three pelagic species are considered: sardine (*Sardina pilchardus* (Walbaum)), anchovy (*Engraulis encrasicolus* (L.)), and horse mackerel (*Trachurus trachurus* (L.)) detected during fisheries acoustics surveys conducted in the Bay of Biscay. A correct classification rate of 57% overall was found for data covering a mesoscale oceanographic environment and including seasonal variability. If space and time scales are reduced this value increased to 98%, emphasizing the value of non-acoustic and *a priori* information.

Key words: acoustics, amplitude PDFs, fish schools, identification, pattern recognition, spectral features.

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Introduction

The acoustic identification of fish shoal species involves several fields of investigation. Solutions to this problem can be important for fisheries resources management where high accuracy of acoustic biomass assessment is required (MacLennan and Simmonds, 1992). Acoustic species identification might also provide useful new observation tools for studies relating behaviour of schooling fish and environmental factors (Scalabrin and Massé, 1993; Swartzman *et al.*, 1994).

Several authors have used a wide range of methods in an attempt to solve this problem. Despite their efforts to identify fish species using acoustic devices, no generally applicable solution has been found for species identification of schooling fish. There are several reasons for this failure. Some methods provide interesting results but their validity is restricted to species with very different schooling behaviours, or to limited geographic regions (Souid, 1988; Rose and Leggett, 1988). Other methods fail because they were developed for analysis of single echoes or for concentrations of fish with observation scales not useful for shoal analysis. Finally, high discrimination and identification scores have been obtained for wideband signals (Simmonds and Armstrong, 1990; Magand, 1994). However, these results relate to controlled experiments or to very limited data, which strongly reduce their potential for generalization to the real world.

The common aspect of all the different methods quoted above is the extraction of useful species identification features from acoustic images of shoals or single backscattered pings from shoals. Indeed, the framework for any acoustic identification is composed of four successive steps: the extraction of descriptive features, the selection of descriptors presenting the highest discriminant power, the choice of classification method, and (finally) validation. If it is assumed that backscattered signals from shoals contain the information required to identify fish species, then the feature extraction should be able to quantify this information with optimal criteria with respect to discrimination or classification methods. In this paper, priority was given to methods of feature extraction for data from narrow-band vertical

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echo-sounders. The problem was analysed under two different aspects. The first concerns the analysis of single shoals, regardless of the environment in the vicinity of the shoal. The second aspect introduces shoal density descriptors in order to provide insights into the spatial distribution of species.

Experimental data collection

Experimental data were obtained at sea using a 38 kHz narrow-band echo-sounder with 20 logR TVG correction, 1 ms pulse duration, and a transducer with $8° \times 8°$ beam width. The echoes were processed using the INES-MOVIES system (Diner *et al.*, 1989) for digitizing (0.10 m vertical sampling) and storing echo-sounder signals. Amplitude values and echo-integration thresholds were standardized over the surveys in order to get the same echo-level response for different power sources.

The data were collected during 11 acoustic surveys performed in the Bay of Biscay from 1989 to 1993 aboard the RV ''Thalassa''. More than 60 000 shoals were detected during the surveys (including both acoustic and trawling transects). In order to label a shoal acoustic image with its true species, the selected shoals were those detected during day-time monospecific trawling operations, i.e. when more than 95% of a catch was composed of a single species, and inside the limits of the trawl sampling volume. The database exploited for acoustic species identification comprised 2702 shoals. This marked reduction in the number of shoals is due to the labelling process required by supervised classification methods. Three pelagic species, among the most common and representative of this region, were considered for acoustic identification: sardine (*Sardina pilchardus* (Walb)), anchovy (*Engraulis encrasicolus* (L.)), and horse mackerel (*Trachurus trachurus* (L.)).

Single-shoal analysis and discrimination

The single-shoal approach uses analysis of shoal descriptors without taking into account any others in the vicinity. The quantitative data used to describe the shoal acoustic image were computed independently of the occurrence of any neighbouring shoal. Three different methods of feature extraction were developed in order to describe fully the acoustic image of a shoal. The first involves the analysis of the whole echogram of a given shoal, which we call the echogram features analysis approach. The second method searches for species differences from an analysis of the echo-amplitude distribution within a shoal; it is called the amplitude probability density function (PDF) approach. The last method explores the spectral analysis of the time-dependence of signal envelopes from the shoals in order to find useful differences among species.

Echogram features analysis

This approach is related to the development of MOVIES-B software (Weill *et al.*, 1993). The MOVIES-B algorithm is able to automatically recognize, through the analysis of acoustic signals, a coherent group of amplitude values belonging to the same physical structure according to spatial energy contiguity criteria. After this real-time automatic recognition process, several groups of descriptors are computed in order to provide information about the acoustic image of the shoal. Acoustic data associated with monospecific trawl samples, including only shoals sampled within the trawl path, were processed by MOVIES-B. Every shoal was labelled, according to trawl results, as sardine (n = 227), anchovy (n = 1113), or horse mackerel (n = 1312), where n is the number of shoals retained in the database. To account for depth-dependent distortions arising from the sounder beam width and pulse elongation effects, corrections were applied to size and shape descriptors (Scalabrin and Massé, 1993). As an outcome of the correction method, any shoal with a *maximum length* $<$*2 beam width at the shoal depth* and an *average height* $\leq \frac{1}{2}$ *pulse duration* was removed from the database. This left 1272 shoals, covering the spring, summer, and autumn periods and distributed as follows: sardine (n = 178), anchovy (n = 449), and horse mackerel (n = 645). The small shoals detected, which were removed from the data set, may be considered to be noise with a negative effect on the discrimination process, since we do not know if they correspond to small discrete shoals or just to shoal boundaries.

Standard statistical tools were used to characterize descriptors. Figure 1 shows the box-plots for some descriptors computed for each species and demonstrates: (1) the average values of descriptors can be quite different for the three species, supporting the hypothesis of a relationship between the behaviour of different species and the description of the shoal obtained by MOVIES-B; (2) nevertheless, there is large intra-species variability, as revealed by the large standard deviations of the descriptors and the many outliers in the box-plots, indicating that each species may be present in a range of shoals of varying size and morphology, bathymetric position, and acoustic energy characteristics.

This uni-dimensional preliminary view of the data suggests that no single descriptor successfully discriminates the three species. Principal components analysis confirmed the trends of Figure 1. The clouds of shoal points in the principal planes overlapped for anchovy and horse mackerel. A step-wise linear regression was performed to find out which descriptors had the highest discriminant power, as indicated by squared multiple correlation coefficients. A linear discriminant model (Morrison, 1976) was finally constructed, using nine continuous descriptors from those computed by MOVIES-B: bottom depth, shoal minimum depth,

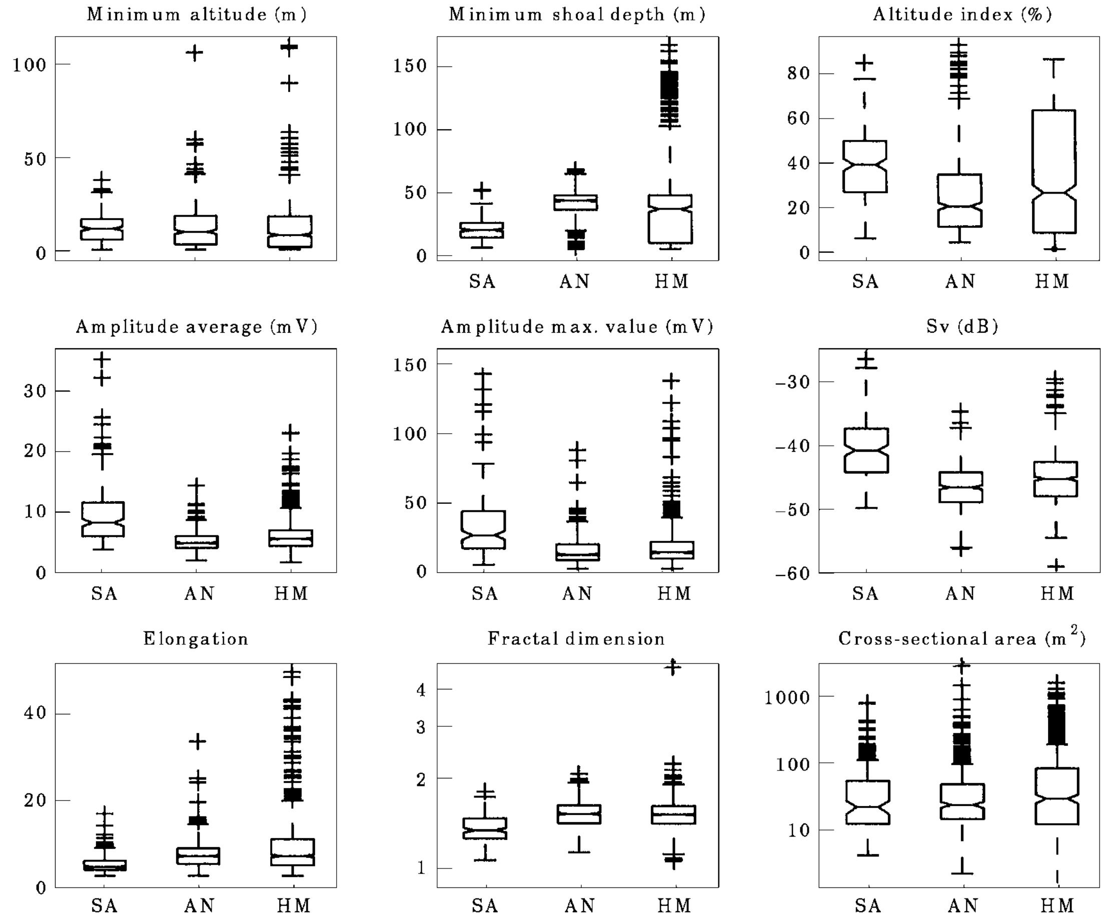

Figure 1. Box-plot graphs of some descriptor value distributions computed by MOVIES-B. SA = sardine; AN = anchovy; HM = horse mackerel.

length, area, elongation, fractal dimension, scattering volume, average amplitude, and amplitude standard deviation. A moderate correlation was found among descriptors, especially for those depending on the echo energy, but the uncorrelated information provided by these descriptors was still important in improving classification rates. The confusion matrix from the discriminant analysis is presented in Table 1. Values on the main diagonal of the matrix represent shoals which were correctly classified for every species. Almost 70% of sardine and anchovy shoals are well classified but horse mackerel shoals are frequently misclassified (Fig. 2). The overall correct classification rate is around 57%, a very low value given that these results refer to the whole training set of shoals and not just to a test subset. Nevertheless, a single discriminant function computed using the same descriptors is effective in discriminating between sardine and anchovy shoals. The overall classification rate then increases to 96%, which is a very high score since it was computed using a test subset composed of 30% of the shoals selected at random.

Table 1. Confusion matrix of the multiple discriminant analysis. Figures are the number of shoals from each species (true class) distributed over predicted classes as the final result of decision rules computed by discriminant analysis.

	Predicted class			
True class	Sardine	Anchovy	Horse mackerel	Total
Sardine	120 67%	25 14%	33 19%	178 100%
Anchovy	27 6%	330 74%	92 20%	449 100%
Horse mackerel	115 18%	264 41%	266 41%	645 100%
Total	262	619	391	1272

These results show that the feature extraction process implemented by MOVIES-B is useful for the identification of sardine and anchovy shoals, but it is not sufficient in a multispecies environment where horse

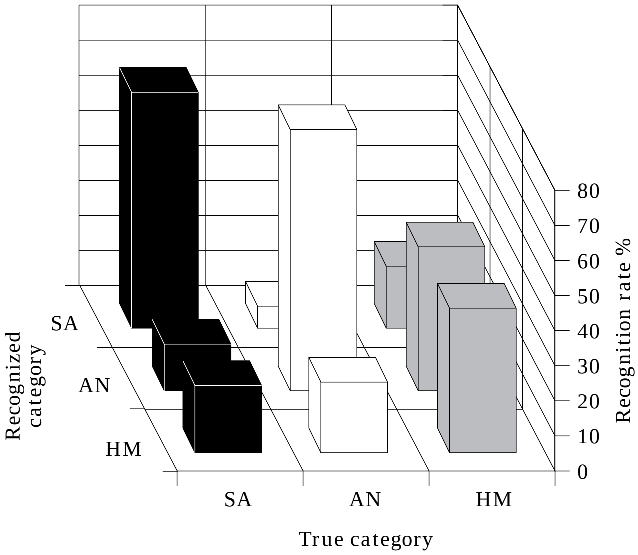

Figure 2. Three-dimensional plot of the confusion matrix values from the discriminant analysis. SA = sardine; AN = anchovy; HM = horse mackerel.

mackerel shoals are present. One of the problems with this approach is the low degree of accuracy provided by standard vertical echo-sounders, which might not be compatible with the scale required to observe inter-species differences in shoaling behaviour.

Amplitude PDFs approach

This type of analysis looks at the echo amplitude PDF from single shoals. It is assumed that shoal species can be distinguished by their echo amplitude PDF signature. Observed PDFs are compared with theory using a χ^2 goodness-of-fit test. This approach has been used successfully to classify sea-surface radar images (Delignon, 1993). Data-handling methods and first results of this approach may be found in Scalabrin and Lurton (1994): (1) shoals must first be selected by size, since a minimum number of amplitude values is needed for goodness-of-fit methods. The number of shoals used in this approach was: sardine (n=80), anchovy (n=91), and horse mackerel (n=84). (2) The shoal echo-amplitude PDF depends on independent samples. For overlapping pings it may be assumed that fish are moving randomly from one ping to another and inter-ping independence is ensured. Within a single ping, however, because of signal oversampling, the samples are not independent. This problem was solved using a non-parametric procedure called a *run test* (Bendat and Piersol, 1986) in order to resample the signal up to statistical independence. (3) Preliminary results, using Pearson's $\sqrt{\beta_1}$, β_2 chart (Stuart and Ord, 1987), show that, although some shoal amplitude distributions may correspond to the Rayleigh distribution, this is seldom the case. Many shoal amplitude probability distributions fall between the Pearson type I lower limit and the lognormal curve (Pearson region VI).

In order to study these preliminary results thoroughly, the Rayleigh and the Beta Type I distributions were fitted to empirical data for each shoal and their goodness-of-fit assessed using a χ^2 test. The χ^2 statistic provides a measure of the discrepancy between observed and expected frequencies. However, there are numerical problems with this test when the right-hand tail of the empirical distribution is sparse. There is no straightforward method to solve this problem, hence the χ^2 test was applied using cumulative distribution functions truncated at the 0.95 cumulative frequency point, at a 0.05 level of significance, with the degrees of freedom set according to the number of parameters estimated for each fit and the number of cumulative distribution bins.

Table 2 presents the results of the χ^2 goodness-of-fit test for the Rayleigh and Beta Type I distributions for each species. It is clear that the Rayleigh distribution is not a good fit to these observed data; the alternative hypothesis cannot be rejected in the case of 123 shoals from a total of 135, and there are similar results for all species. The Beta Type I distribution seems more appropriate, especially for sardine and anchovy shoals. Nevertheless, for more than one-third of horse mackerel data, the Beta distribution does not fit the data.

The most important point for species identification using this approach is the differences observed in the estimated parameter values (Fig. 3). The Beta Type I distribution is characterized by four parameters: **a** and **b**, which represent the range, and **p** and **q**, which are shape parameters. No significant differences were found among species for the mean estimates of **b** and **q**, but the

Table 2. χ^2 goodness-of-fit test results. n is the total number of shoals analysed. Figures under the columns $[H_0{:}F=F_0]$ represent the number of shoals where the null hypothesis can be accepted at a level of signification $\alpha=0.05$. Figures under the columns $[H_1{:}F\neq F_0]$ represent the number of shoals where the alternative hypothesis cannot be rejected, i.e. the observed frequency distribution F_0 of amplitude values cannot be fitted by the theoretical distribution *F*.

		Beat Type I		Rayleigh	
Species	n	$H_0{:}F=F_0$	$H_1{:}F\neq F_0$	$H_0{:}F=F_0$	$H_1{:}F\neq F_0$
Sardine	39	32	7	2	37
Anchovy	34	30	4	8	26
Horse mackerel	63	38	25	3	60
Total	136	100	36	13	123

p values may be useful to discriminate sardine and **a** values to discriminate anchovy.

In conclusion, the amplitude PDF approach seems to give interesting results, since for the first time a clear difference between anchovy and horse mackerel shoals was observed. The weakness of this kind of analysis is the large number of amplitude values required which can only be obtained when large shoals are detected. However, when such information is available, it could be used as additional information to confirm or reject classification results from other methods.

Spectral analysis approach

The temporal envelope of signals backscattered from shoals is often characterized by fluctuations varying in frequency. Visual inspection of such envelopes suggests that amplitude fluctuation characteristics could be used to separate species. To test this hypothesis, a spectral method proposed for sea-floor backscattered signal identification (Pace and Gao, 1988) was adapted for our present purposes (Scalabrin and Lurton, 1994). This method compares the relative energy contained in various frequency bands of the power spectrum. The most important findings can be summarized as follows: (1) the intra-species spread of spectral descriptor values may be important, especially for horse mackerel and sardine, although the values for anchovy are less variable; (2) the inter-species separation, especially between sardine and horse mackerel shoals, is interesting, although anchovy shoal values are positioned in the region of overlap between the other two species; (3) some clear trends were observed which verify the visual differences in backscattered amplitude envelopes. For instance, horse mackerel shoals produce lower frequency fluctuations than do sardine shoals.

An important limitation is that a minimum echo length is required for spectral analysis, reducing the number of shoals which may be analysed by this approach. Moreover, the short echoes usually produced by shoals is a critical limitation in using more complex spectral methods. Therefore, the statistics of spectral descriptors were not sufficient to improve the overall species identification, but they provided interesting insights allowing them to be used as a secondary classification key.

Potential use of image analysis for species identification

The tools described above for single-shoal analysis do not take into account the relationships between a given shoal and its environment characterized by adjacent shoals. However, it seems that the shoal vicinity is an important feature used by fisheries acousticians or fishermen when trying to identify shoaling species from the appearance of whole echograms. In order to estimate the information provided by this empirical identification process, entire sequences of data from trawling operations were processed using a commercial image-processing package (Optilab(TM)/24 2.1). Thirty-four trawling sequences were selected to test this approach, distributed as follows: sardine (n=12), anchovy (n=11), and horse mackerel (n=11), where n is no longer the number of shoals but the number of processed sequences. For this processing method, the complete trawl path was not taken into account, only sequences corresponding to monospecific catches.

Figure 4 presents an example of the spatial distribution, along a trawling sequence, of shoal barycentre coordinates for each species. The image processing provided three new descriptors supposed to quantify the spatial distribution differences clearly observed in Figure 4: the average distance (m) from the first up to the eighth nearest neighbours, the density of shoals (number km^{-1}), and the shoal influence area ratio (IAR). The IAR was computed as the ratio between the detected area of a given shoal and the shoal influence area computed after successive dilations of the former area and repeated until the entire shoal boundary is in contact with other shoal boundaries dilated simultaneously. This parameter could provide interesting insights into species behaviour, reflecting the average living space required by shoals for their spatial dynamics.

Table 3 gives the statistics for these descriptors. As expected, large values of the average distance between the two nearest neighbours (NND_2) were found for sardine, while anchovy has the lowest values; obviously, there is a negative correlation between shoal density and the nearest neighbour distances, and a positive correlation between shoal density and the IAR. Low values of IAR for sardine mean that shoal areas are relatively small compared with the empty space around the shoal. Space requirements are probably higher for sardine than for anchovy shoals. It is important to note

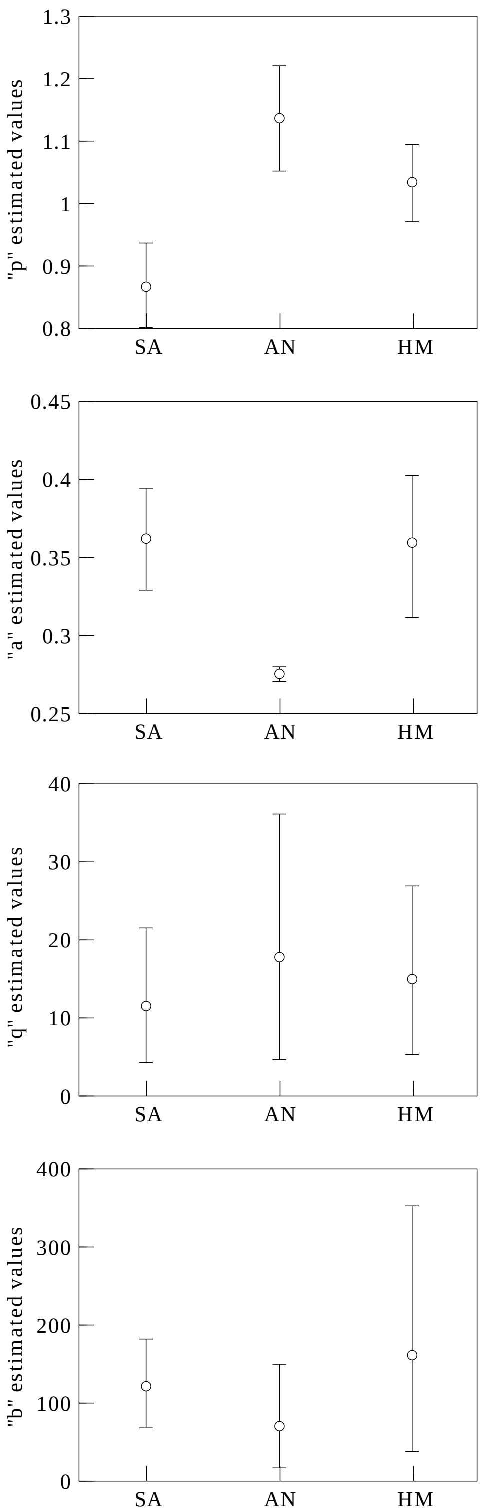

Figure 3. Estimated mean (○) and 90% confidence interval of parameters **p**, **q**, **a** and **b** from Beta Type I fit. Mean estimates were computed from fitted distribution functions when the null hypothesis was accepted, according to Table 2 values. SA = sardine; AN = anchovy; HM = horse mackerel.

that only sequences with the same bottom depth were used to compute IAR, which explains the lower n in Table 3.

In conclusion, our results suggest large differences in the spatial distribution behaviour among species but, once more, the large spread of values around the average means that shoal behaviour is not stable enough to allow discrimination with a high probability of correct classification.

Discussion and conclusion

In summary, all the methods described above provide interesting insights for classification and species identification purposes. Some clear trends were observed and to some extent the three species present characteristic shoaling behaviours described by the different extracted features and methods.

However, our results are not yet at the level required for a high probability of species identification. Two main reasons may be advanced to partially explain the relative lack of success: (1) for the purpose of measuring real species differences in the internal structure of shoals, standard narrow-band echo-sounders used for shallow-water pelagic work are inflexible and unsuitable in certain instrument features, such as the beam width, pulse duration, and frequency. These echo-sounders usually operate with a large single beam ($\approx 10°$), resulting in low angular resolution which seriously compromises the measurement of shoal morphology. In addition, the 1 ms pulse duration provides 0.75 m of vertical sampling distance, contributing to poor spatial resolution. Moreover, the use of a narrow frequency bandwidth limits the quality of information that could be provided by the signal spectrum. (2) Data used to improve feature extraction were observed within a mesoscale oceanographic environment comprising sub-regions with different physical and hydrographical parameters; furthermore, the data covered a long period of time (five years) and different seasons. The consequences of this large range of environmental conditions are exemplified by the variability observed for horse mackerel. This species displays different kinds of behaviour, probably related to environmental conditions and feeding habits, which may change the shoal structure giving a large range of acoustic characteristics that overlap those of other species. It would be possible to reduce this variability by concentrating the sampling in a small region during the same season. Some attempts to perform a local discrimination were made using data collected in the same area and at the same time of year during three inter-annual surveys. The correct classification rate increased to 98% overall, which is much better than the 57% rate computed using all shoals. This result supports the intuitive hypothesis that an area-time approach could provide better species identification by

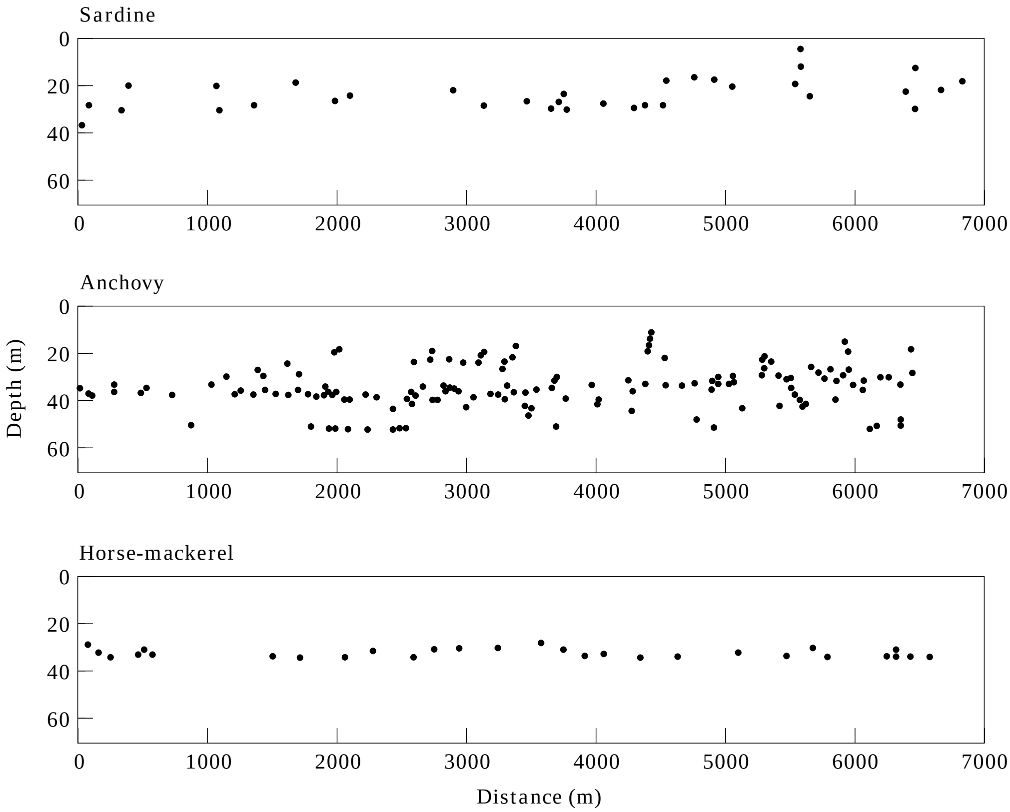

Figure 4. Spatial distribution, along a trawling sequence, of shoal barycentre coordinates. The bottom depth was 46 m for sardine, 68 m for anchovy, and 48 m for horse mackerel. Species identification was provided by a midwater trawl with 22 m of vertical opening.

Table 3. Average ($\bar{x}$) and standard deviation (S_x) of image-processing descriptor values. n is the number of monospecific trawling sequences processed. NND_2 is the two nearest-neighbour average distance. Density is the number of shoals km^{-1}. IAR is the influence area ratio, a low value indicating that shoal area is relatively small compared to the empty space around the shoal.

Species	NND_2 (m)			Density (no km^{-1})			IAR (%)		
	n	$\bar{x}$	S_x	n	$\bar{x}$	S_x	n	$\bar{x}$	S_x
Sardine	12	160	80	12	11	4	12	1.3	0.9
Anchovy	11	69	67	11	47	32	3	4.5	3.8
Horse mackerel	11	95	51	11	20	9	6	3.4	1.9
Total	34	109	77	34	26	24	21	2.4	2.3

combining non-acoustic and acoustic information. Nevertheless, the impressive value of 98% must be interpreted with care. In this exercise, species were not equally represented and anchovy shoals were predominant (almost 90%). The misclassification of approximately 40% of sardine and horse mackerel shoals is related to their small number. In order to validate this approach, more data for ground-truth are required. The monospecific database of more than 1000 shoals presented here is not sufficient for this purpose in the Bay of Biscay surveys.

To overcome these difficulties even partly, it would be necessary to improve the flexibility of acoustic devices and to include non-acoustic or *a priori* information in the analysis. Each set of circumstances should be addressed individually, meaning that no general solution is ever likely to be attained using presently available technology.

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