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Consistency in the correlation of school parameters across years and stocks

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Acoustic surveys have been undertaken in different parts of the waters around Europe. In this paper we consider those taking place in NE Atlantic waters – off the NE Scottish coast, the Bay of Biscay and off the Spanish Atlantic coast – and in the Mediterranean Sea – the Catalonian Sea, the Gulf of Lion and the Aegean Sea. Retained school variables were: corrected school length (m), school height (m), school area (m^2), school perimeter (m), school energy (Nautical area scattering coefficent, S_A), school density (energy vs. area), school depth (m) and bottom-depth-under-school (m). STATIS (Structuration de Tableux à Trois Indices de la Statisque), a multi-table analysis based on the Principal Component Analysis was used to analyse the correlation in different schools, parameters and intra- and interstock relationships. In all stocks, the first three axes extracted explained between 86.89% (Sete) and 91.84% (Aberdeen) of the total variance, because the annual variability present in the correlation structure of each stock is not widely dispersed. In all stocks, the first factorial axis was typified by the morphological variables (school length, school height, school area and school perimeter), which showed a very clear pattern with all of them being closely related. There were major differences between all stocks in regard to the general correlation relationship of the energetic variables analysed i.e. school energy and school density. Energy and density showed less variability than the morphological variables in all stocks with the exception of one survey. There were some differences between stocks in relation to the correlation of bathymetric variables. In all cases, school density and, to a lesser extent, school energy were opposed to the bathymetric variables, so that schools with higher densities would be located near the surface and in shallower areas. A complete analysis of all the surveys of each stock showed a homogeneous pattern which was very similar to most of the stocks considered separately. All morphological variables are well grouped and show a strong positive correlation. In general, therefore, all the schools analysed increased and decreased equally in all their dimensions. Both bathymetric variables are strongly correlated.

Keywords: acoustic survey, correlation, inter-stocks variability, intra-stocks variability, school bathymetry, school energy, school morphology, STATIS.

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Introduction

One of the most typical behavioural traits of most pelagic fishes is schooling: forming schools which in turn tend to make clusters of schools. There are a number of different reasons for this behaviour (Kennedy and Pitcher, 1975; Pitcher, 1983; Fréon and Misund, 1999). A lot of schooling pelagic fishes have a high level of commercial interest and are subjected to intensive fishing and the typical schooling behaviour might influence stock assessment methods (Ulltang, 1980; Aglen, 1994). The stocks of these pelagic species constantly reflect important changes due to both natural causes and human impact which leads to diminishing numbers. This decrease in the stock over time must have some effect on different aspects of the aggregate behaviour of the fish: schools may become smaller, have declining densities or be spaced further apart, etc. This is why a greater knowledge of these aspects is essential for the sustainable management and exploitation of the fisheries.

Based on this premise, the European Union funded the project CLUSTER (FAIR CT 96 1799). Its main purpose was to try and understand how the aggregation patterns of different species of pelagic fishes may change in relation, among others factors, to stock size, stock-age distribution, exploitation patterns and environmental variables. These questions were examined by means of comparative studies of different stocks of several pelagic fish species in a number of geographical areas supporting different fishery activities. Acoustic surveys performed for stock evaluation were used to obtain the databases. The following species and stocks were analysed: herring (*Clupea harengus*) from Scottish waters, anchovy (*Engraulis encrasicholus*) and sardine (*Sardina pilchardus* Walbaum) from the Spanish Atlantic coast, Bay of Biscay, Spanish Mediterranean (Catalonia and Valencia), Gulf of Lion and Aegean Sea, as well as other pelagic species such as the horse-mackerel (*Trachurus trachurus*), mackerel (*Scomber scombrus*), sardinella (*Sardinella auritus*), etc.

The aim of this study was to analyse the correlation among different school parameters and their intra- and interstock relationships. A novel analysis in fisheries sciences called STATIS, which performs a multi-table analysis, was used. This method was developed by Lavit (1988) and Lavit *et al.* (1994) and is based on the Principal Component Analysis.

Material and methods

School database

The school database aimed to characterize schools and clusters of schools in European pelagic fish stocks and their relationships with population abundance. The original data of the acoustic surveys undertaken in different locations of European waters were recorded in different ways which are summarized in Table 1. The French surveys used the INES/MOVIES acquisition and processing system (Diner *et al.*, 1989); the Scottish and Greek surveys processed data by means of automated Image Analysis (IA) systems (Reid and Simmonds, 1993) while the Spanish surveys the data were recorded on paper. The extraction of the schools was done automatically for the French, Scottish and Greek surveys. The Spanish surveys employed a semi-automatic method which consisted of (a) scanning the images (echograms on paper); (b) processing them with commercial software and (c) allocating backscattering energy according to the integram line. ICES (2000a) reviews each method used by all the CLUSTER partners.

No matter which method was used several school descriptors were compiled. Since school geometry could only be properly derived when the relation between school size and the depth at which it was located and the transducer beam angle was higher than 1.5, morphological variables such as length, height, and area were corrected according to the Noël Diner algorithm (Diner, 1998; ICES, 2000). Schools for which real size was determined were called "corrected" schools and the schools whose real size could not be extracted were termed "uncorrected" schools. School energy (acoustic-backscattering energy, S_A) was averaged to an EDSU (Elementary Distance Sampling Unit, which was fixed at 1 nmi), according to the following transformation:

$$S_{A\ (\text{school})} = S_{A\ (\text{integram})} * (\text{EDSU distance (m)}/\text{school length (m)}) = \text{NASC (Nautical area scattering coefficient)}$$ (ICES, 2000b)

In those surveys where the number of pings was not available a simple assumption of constant ping rate and straight line steaming was done and, therefore, this quantity could also be expressed in terms of the length of the school in relation to the total length of the EDSU. In addition, French data were transformed into S_A units applying the following conversion factor:

$$E_N = 0.0232 * S_A * D$$

where D is distance expressed in nmi.

Data analysis

Only those schools whose morphological variables were able to be properly measured were analysed (i.e. "corrected schools"). Retained variables were: corrected school length (m), school height (m), school area (m), school perimeter (m), school energy (Nautical area scattering coefficient, S_A), school density (energy vs. area), school depth (m) and bottom-depth-under-school (m)

Table 1. Main characteristics of the analysed surveys.

Area	Acronimus	No. surveys	Period	Years	School extraction	School measurement	No. nmi analysed	No. retained schoos	Aver. no. school/nmi
Off Scotland	Aberdeen	6	Summer	1991; 1993–97	Full IA	Automatic IA	13 427 (2887)	8983	3.11
Bay Biscay (France)	Nantes	4	Spring	1991–92–94–97	School algorithm	School algorithm	2495 (2141)	10 713	5.00
Off Spanish Atlantic coast	Coruña	5	Spring	1992–93; 1995–97	Scanning	Manual-IA	5354 (899)	2066	2.30
Catalonian Sea	P. Mallorca	4	Fall	1992–93; 1995–96	Scanning	Manual-IA	2353 (583)	2014	3.45
Gulf of Lion	Sète	4	Summer	1993; 1995–97	School algorithm	School Algorithm	905 (686)	4352	6.34
Aegean Sea	Heraklion	3	Fall	1996A–96B; 1997	Scanning	Automatic IA	966 (445)	2686	5.90

(Figure 2). A simple description was done by means of boxplots performed on each variable and survey. Because of the skewness of these variables further analyses were done on log-transformed variables.

In order to make full comparisons among the school parameters from the surveys either within each area or among areas which comprised a different number of schools and surveys, the STATIS (Structuration de Tableux à Trois Indices de la Statisque) system was used (Lavit, 1988; Lavit *et al.*, 1994). This is a PCA-based method which enables the joint analysis of many tables. From each school data set of each survey an average correlation matrix called the "compromise" is calculated. Then a PCA is performed on this matrix and the structure in each initial matrix (i.e. from each school data set of each survey) in the factorial space of the compromise is analysed. This factorial space is a common space in which the correlation structures in the different matrices can be compared at one time. This method has already been used in fisheries science to explore the variability in species assemblages over the years to be found in bottom-trawl survey data (Gaertner *et al.*, 1998).

Results

Intra-stock variability

The first factorial axis of the PCAs carried out on the compromise matrix of each stock explained a high percentage of variability: higher than 50% in all cases (Table 2). In all stocks the first three axes extracted explained between 86.89% (Sète) and 91.84% (Aberdeen) of the total variance because the annual variability present in the correlation structure of each stock was not widely dispersed. This indicates that there is a strong general pattern in each stock. Figures 3, 4 and 5, show the graphic representation of each variable analysed on the plane i.e. the position in the compromise matrix and the trajectories in each annual matrix. The different kinds of variables analysed, morphological, energetic and bathymetric, presented slight differences between the stocks although there was a pattern common to all of them.

In all stocks the first factorial axis was typified by the morphological variables school length, school height, school area and school perimeter, which showed a very clear pattern with all of them being closely related (Figures 3, 4 and 5). There is a strong correlation between all the variables which indicates that the school shape is always proportional e.g. the larger the length, the greater the height, area and perimeter. This relationship in school shape is unrelated to the species of pelagic fishes that comprise it since most of the databases analysed are not unispecific but multispecific, with the

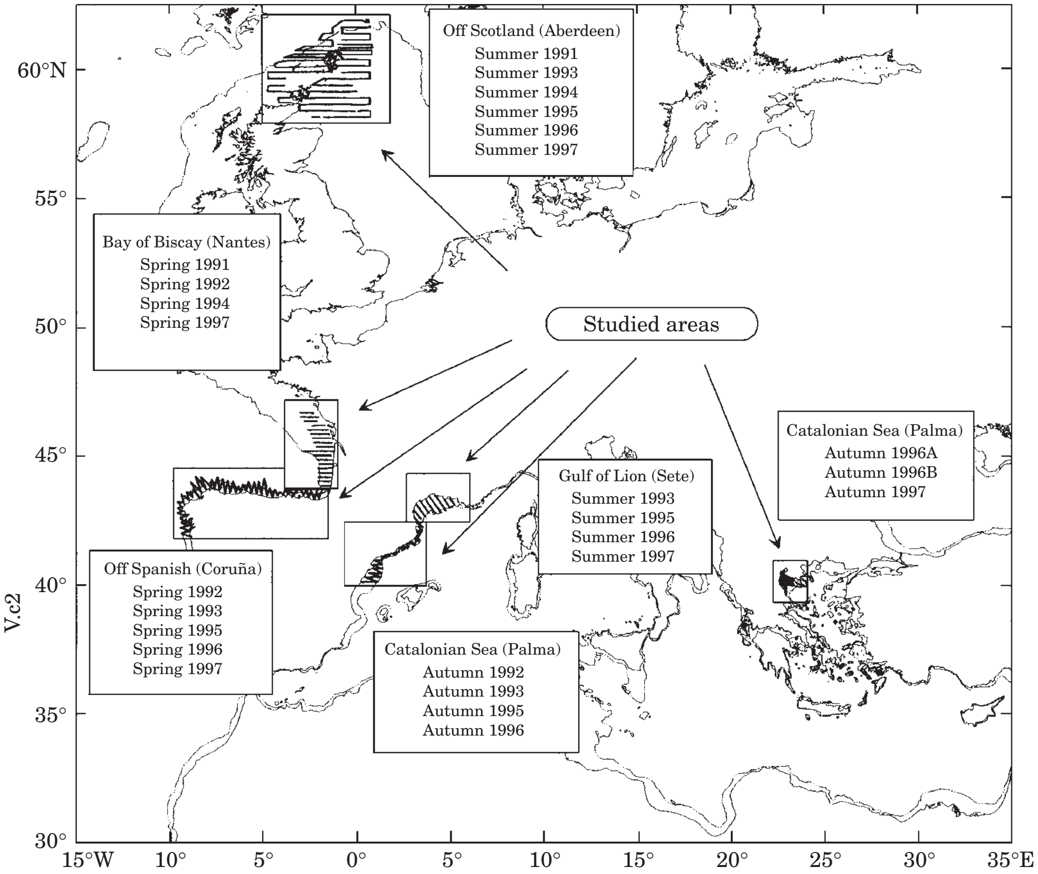


Figure 1. Geographical areas and years of the different surveys analysed.

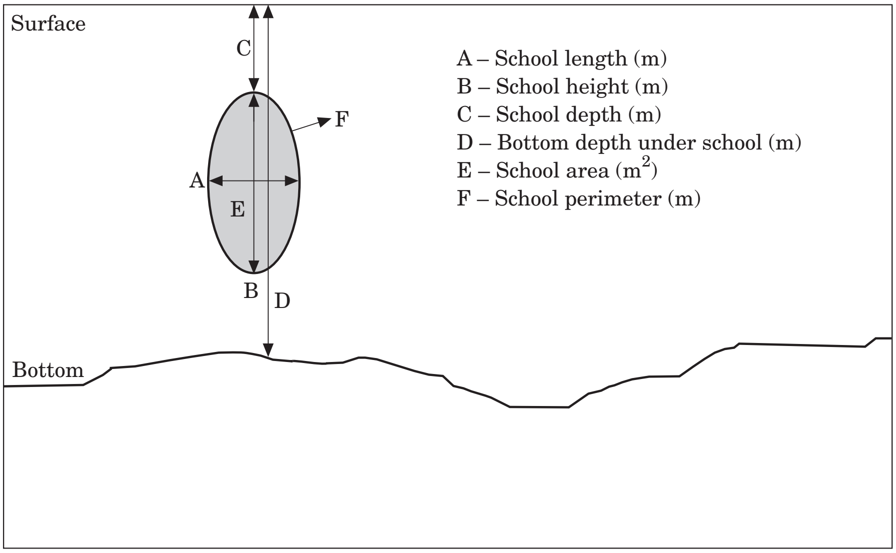


Figure 2. School morphologial and positional parameters extracted from the echograms.

Table 2. Explicated variance (%) of the axis I, II and III of the principal component analysis (PCA) for the different stocks.

	Aberdeen	Nantes	Coruña	Palma	Sète	Heraklion	All stocks
Axis I	52.72	58.19	56.99	50.39	57.70	58.43	51.02
Axis II	22.00	24.39	20.93	22.60	21.31	24.06	23.51
Axis III	17.12	8.83	9.20	14.30	7.88	8.71	12.53
Total I/II/III	91.84	91.41	87.12	87.29	86.89	91.20	87.06

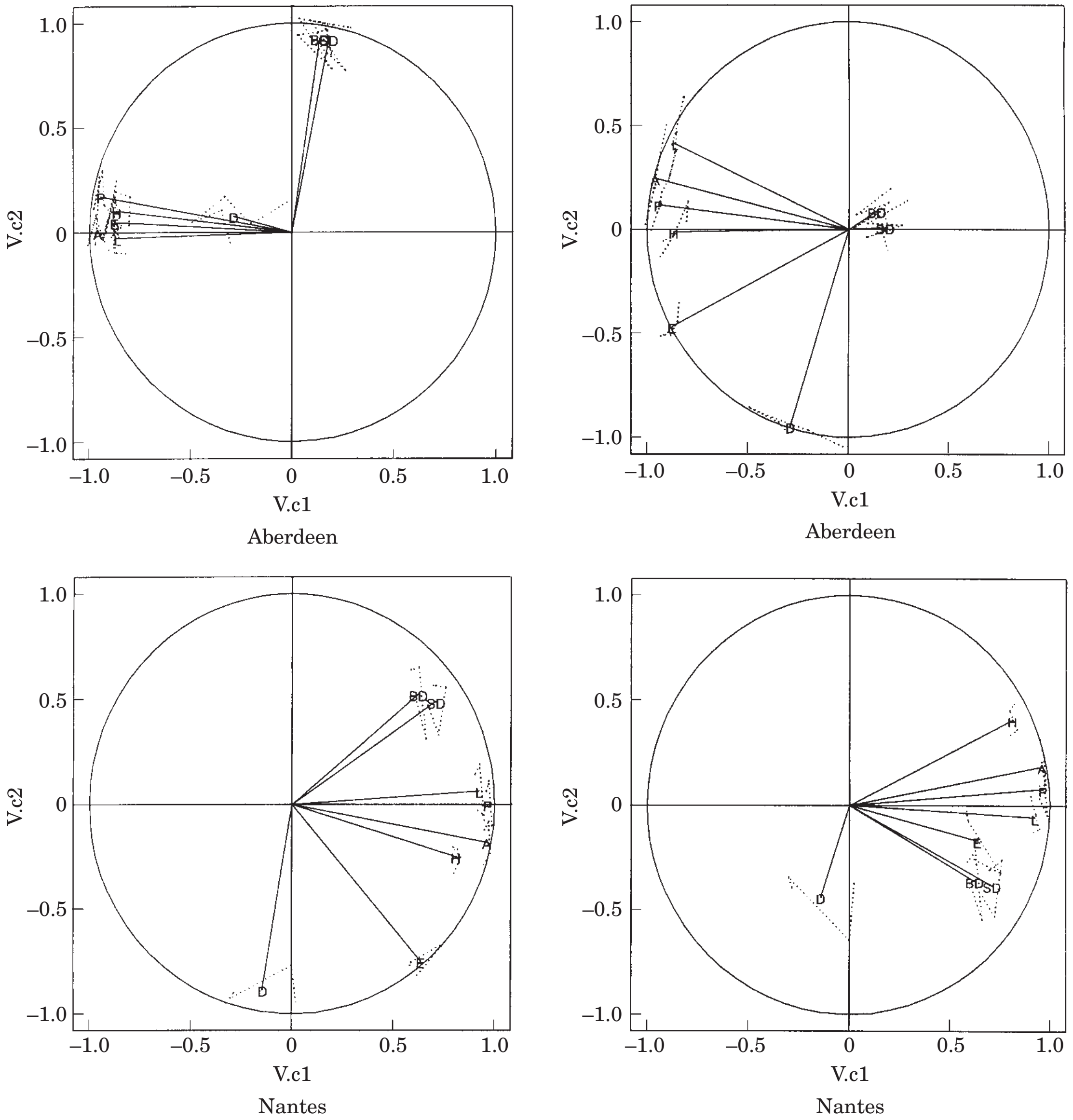
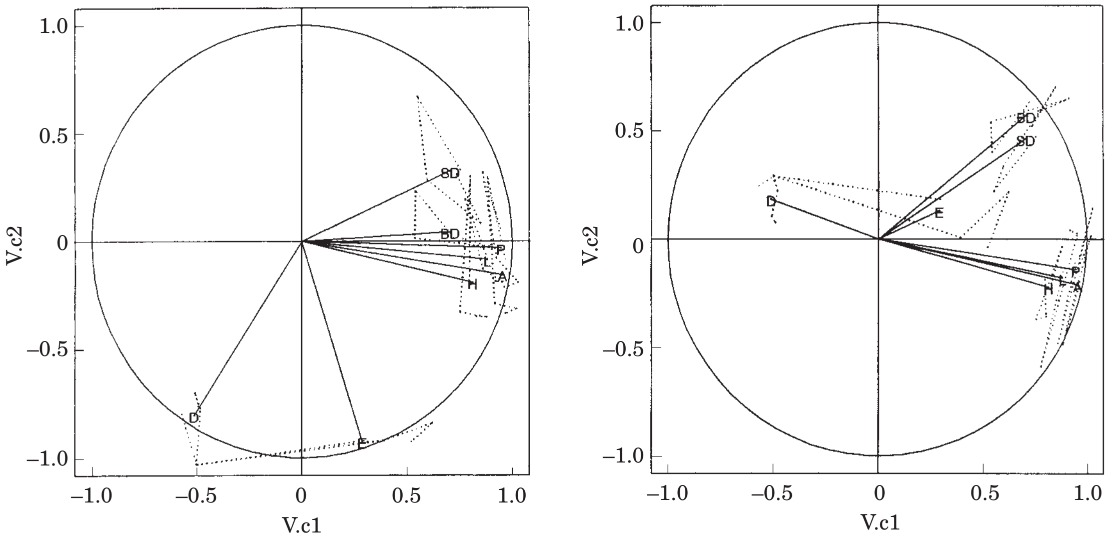
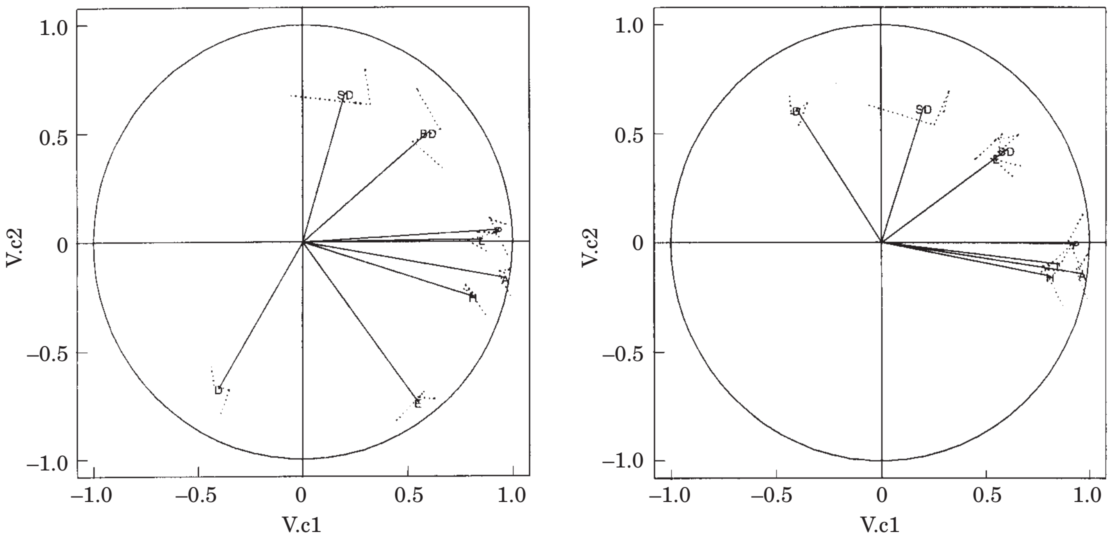


Figure 3. Joint analysis of the school parameter correlation matrix for surveys of Aberdeen and Nantes. Representation of the school parameters (i.e. variables) in the factorial planes (1,2) and (1,3) of the compromise matrix V. (L: School length; H: School height, A: School area; P: School perimeter; E: School energy; D: School density; SD: School depth; BD: Bottom-depth-under-school.)



Coruña Coruña



Palma de Mallorca Palma de Mallorca

Figure 4. Joint analysis of the school parameter correlation matrix for surveys of Coruña and Palma de Mallorca. Representation of the school parameters (i.e. variables) in the factorial planes (1,2) and (1,3) of the compromise matrix V. (L: School length; H: School height, A: School area; P: School perimeter; E: School energy; D: School density; SD: School depth; BD: Bottom-depth-under-school.)

exception of Aberdeen, which has analysed databases that are made up of herring only and Heraklion whose schools consist primarily of sardine or anchovy.

The foremost feature of all morphological variables in all the stocks was the highest dispersion, mainly in length and perimeter (Figure 6). The schools found off the Spanish Atlantic coast and the Bay of Biscay exhibited the largest size and the highest variability in all morphological variables (Figure 6). In most of the stocks some interannual variability was to be expected, which pointed to changes in the size of the schools each year, although not in their morphology due to the strong correlation among the morphological variables.

There were major differences between all stocks in relation to the general correlation relationship of the energetic variables analysed viz. school energy and school density. Both variables showed the opposite correlation with bathymetric variables to a different extent as compared to the schools of Nantes, Coruña, Palma and Sète. More schools with higher densities or

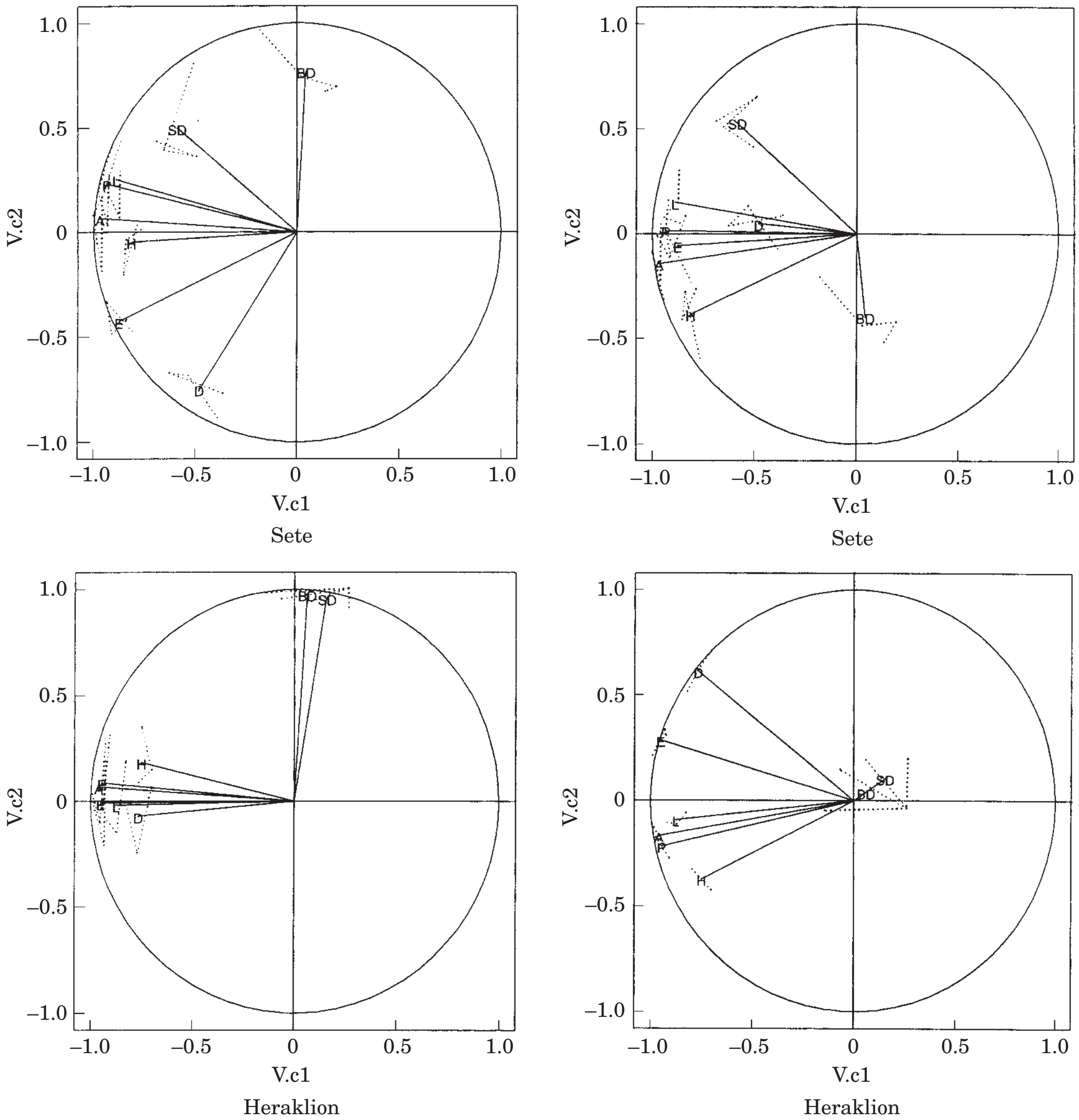


Figure 5. Joint analysis of the school parameter correlation matrix for surveys of Sète and Heraklion. Representation of the school parameters (i.e. variables) in the factorial planes (1,2) and (1,3) of the compromise matrix V. (L: School length; H: School height, A: School area; P: School perimeter; E: School energy; D: School density; SD: School depth; BD: Bottom-depth-under-school.)

with more energy or with both of these features are found closer to the surface. In addition, in Nantes, Coruña and Palma, school density and school size correlated inversely, i.e. more density involved less size and depth, with the school energy being located between school density and the all morphological variables (Figures 3, 4 and 5). In contrast, the schools of Aberdeen and Heraklion showed a strong correlation between the morphological variables and energy, and, to a lesser extent, with density (Figures 3, 4 and 5), so that the larger the school the more energy and density it has. The schools of Sète also showed a positive correlation between morphological and energetic variables but this was less important than those of Aberdeen and Heraklion (Figure 5).

Energy and density presented less variability than the morphological variables in all stocks except one. In this case, the acoustic survey 96B of Heraklion, the source of the highest variability in energy and density (Figure 6) was one sardine school whose energy was about three times higher than the previous school with the highest energy value of this survey.

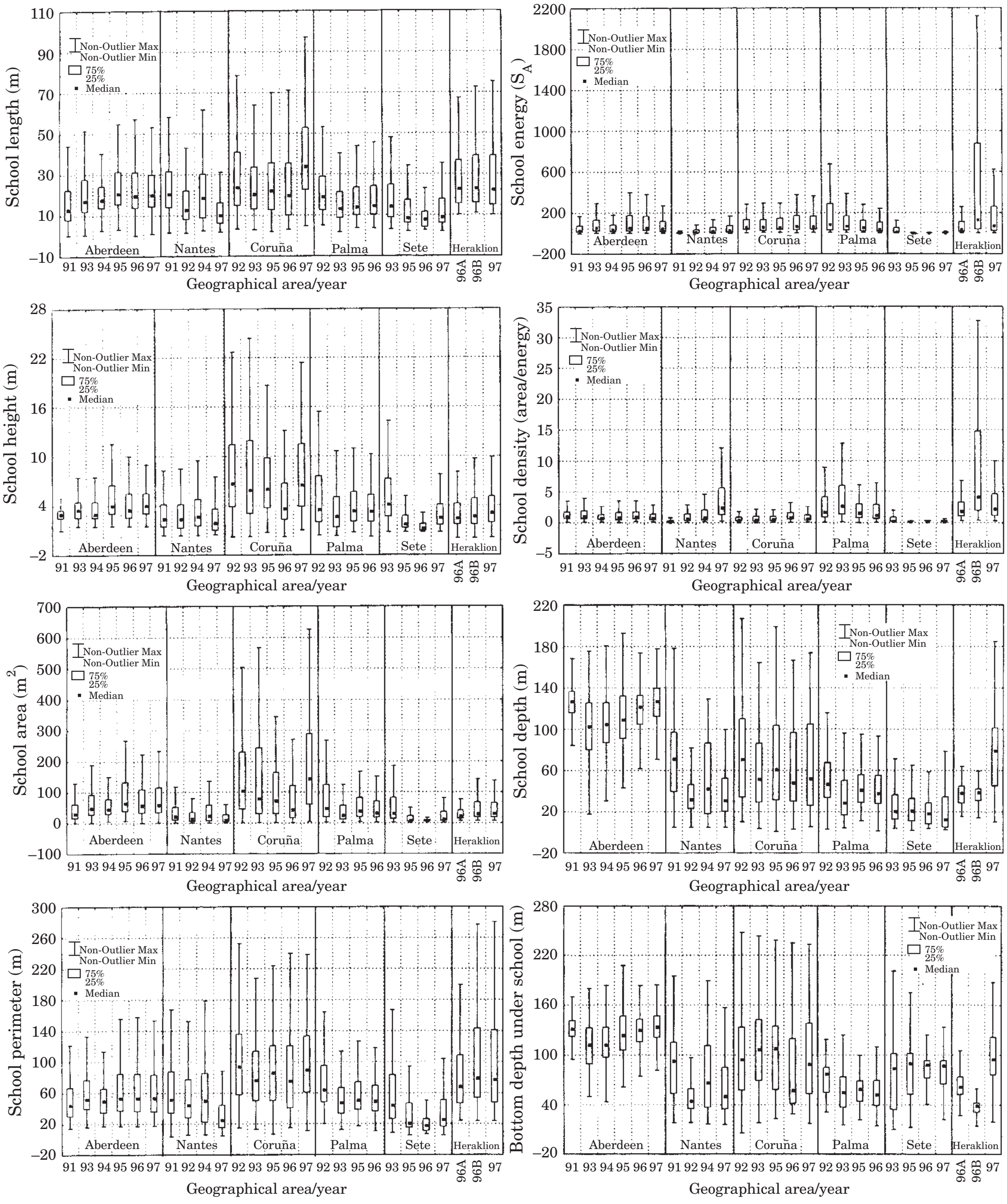


Figure 6. Box-plots of all variables by area and year.

The schools of Aberdeen, Nantes and Heraklion presented strong correlations in both bathymetric variables – greater bottom depth under the school, greater school depth – while in Coruña, Palma and mainly Sète the correlation was less important i.e. the schools were not deeper because there was more depth (Figures 3, 4 and 5). Only in the schools located off the Spanish Atlantic coast (Coruña) was there an apparent positive correlation between morphological and bathymetric variables. This was mainly with bottom depth; larger schools being located in deeper areas and at greater depths than in all other stocks (Figures 4 and 6).

In all cases, school density and, to a lesser extent, school energy were opposed to the bathymetric variables, so that schools with higher densities would be found near the surface and in shallower areas. This pattern was very homogeneous in all stocks in spite of the different mean depths encountered: the Aberdeen schools being the deepest (located mainly between 90 and 130 m depth) and the Sète schools, the shallowest (between 10 and 40 m), although the bottom depth in the Sète area is generally over 50 m (Figure 6). There were significant differences between the geographical areas where the schools were found in terms of both the bottom depth and the characteristics of the continental shelf in each area studied. The deepest waters were found in the Aberdeen surveys at between 100 and 140 m depth and the shallowest – between 45 and 70 m – off Palma (Figure 6).

Inter-stock variability

A complete analysis of all the surveys of each stock showed a homogeneous pattern which was very similar to that of most stocks considered separately. Similarly, the first three PCA axes carried out on the compromise matrix explained much of the total variance (87%), of which the first factorial axis extracted explained 51% (Table 2). The first factorial axis represents the school size/shape and it is characterized by all the morphological variables, just as occurred in each stock separately. All the morphological variables are well grouped (Figure 7) and show a strong positive correlation. So, in general, all the schools analysed increased and decreased equally in all their dimensions. The second factorial axis contrasts the bathymetric variables (school depth and bottom depth) with school density (denser schools are closer to the surface) (Figure 7). Energy is found between density and all the morphological variables. Both bathymetric variables are strongly correlated. The trajectories of the point-variables (solid lines in Figure 7) show some variability which, however, is not enough to change the average correlation structure. The trajectories of school and bottom depth do not overlap with any others and the trajectories of the morphological parameters overlap slightly with the those of energy, which, in turn, overlap with those of density.

Figure 7 shows the position of the correlation matrices for all surveys in the first factorial plane of the interstructure matrix. Surveys have very similar first coordinates except for Coruña93. Similar first coordinates mean the there is a similar correlation structure between school parameters of all years and from all areas, as previously analysed. The second factorial axis enables us to construct groups of correlation matrices: one which includes all surveys of Coruña, Nantes and Palma, and another which includes all surveys of Aberdeen (except Aberdeen95), Heraklion97 and Sète96. The rest of surveys of Sète are placed between both groups, while Aberdeen95, and Heraklion 96A and 96B together could not be placed in any group. Although the layout of the different groups cannot be related to a geographical scale – either latitudinal nor longitudinal – in the correlation matrix of the different acoustic surveys of each stock there, nevertheless, seemed to be a strong tendency to group all surveys of the same stock together (Figure 7).

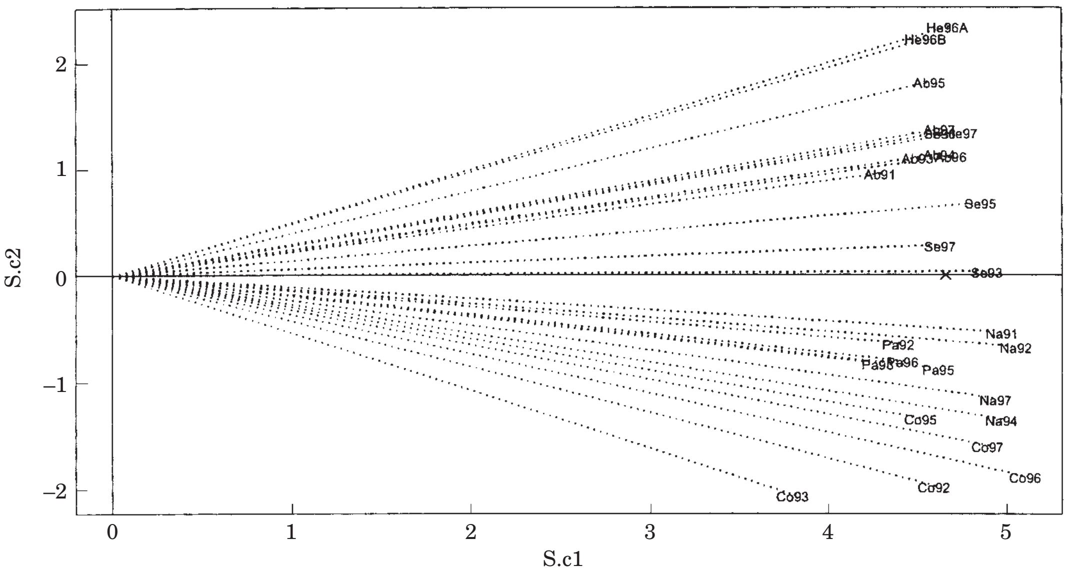
Discussion

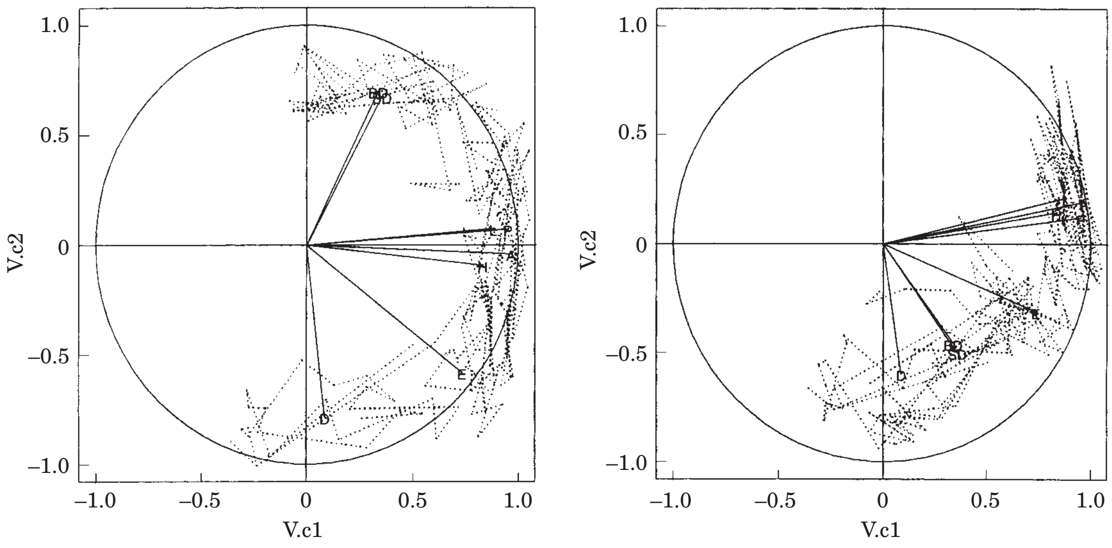
Correlation in school parameters shows a strong common structure between all surveys and regions with slight differences. Three groups of school parameters have been identified: morphological (height, length, area and perimeter), positional (school depth and bottom depth) and energetic (mainly school energy). Correlation is particularly strong between school morphological parameters in the different stocks implying that, in general, schools tend to keep a constant morphology in all geographical areas. This pattern of linear variation in all morphological dimensions is similar in all stocks so that it is unrelated to the different individual characteristics such as the number and kind of species that make up the schools, fishery pressure on them, latitude and longitude, water temperature and water salinity, etc. Others studies also found a similar pattern (Scalabrin *et al.*, 1992; Scalabrin and Massé, 1993) which confirmed the stability in acoustics data on school morphology.

The relationship between school length and school height observed in this work agrees with the pattern cited in other studies where school length is always greater than school height to give the school a discoidal shape (Ohshimo, 1996; Scalabrin and Massé, 1993; Misund *et al.*, 1995; Fréon and Misund, 1999). The strong correlation seen between all morphological parameters would imply great stability in that shape. Patridge *et al.* (1980) also observed that herring schools had a tendency to maintain a stable shape but other authors observed that this discoidal shape varied with the movement of the fish, even over very short time periods (Fréon *et al.*, 1992) or due to their specific composition (Massé *et al.*, 1996).

PCAs carried out on each survey from each geographical area showed that there was temporal stability in the correlation patterns of the school morphological variables from each area. Consequently the interannual variability observed in most of the stocks could be related mainly to school-size differences rather than to changes in school shape. Petitgas *et al.* (2001) found that the yearly biomass fluctuations of each stock could be the reason for the differences in the size of the schools. From the results presented here it can be seen that while the size of schools might change in relation to stock abundance the shape would remain constant.

Energy and density did not correlate with all the other variables, both morphological and bathymetric, in most of the stocks as cited previously by various authors (e.g. Misund, 1993; Scalabrin and Massé, 1993). On the contrary, there was a high correlation, which had not





All stocks

All stocks

Figure 7. Joint analysis of the school parameter correlation matrix for surveys of all stocks together. Representation of the school parameters (i.e. variables) in the factorial planes (1,2) and (1,3) of the compromise matrix V. (L: School length; H: School height, A: School area; P: School perimeter; E: School energy; D: School density; SD: School depth; BD: Bottom-depth-under-school.)

been observed previously, between energy and morphological variables only in the schools of Aberdeen and Heraklion. The differences found in Aberdeen and Heraklion as compared to the rest of the stocks in terms of energy variables could be due to the high rate of monospecificity observed in their databases. Nearly 100% of the Aberdeen schools were herring schools and more than 80% of the Heraklion schools were sardine or anchovy schools. All other stock databases contained schools of a greater number of species or with more multispecificity.

There are several reasons that might explain the differences in the school bathymetric relationships of the different stocks. One of these would be the differences in the vertical distribution preferences shown by different species, as previously cited by Massé *et al.* (1996) in the Bay of Biscay. If each species exhibited a prefered depth, the mono-or multispecificity of the databases could be one of the reasons for the variability between stocks. Another source of variability might be the differences in the climate conditions linked to the presence of seasonal thermoclines. A positive correlation between herring abundance and thermocline depth linked to zooplankton has been noted (Maravelias & Reid, 1997). Thermoclines of each geographical area showed bathymetric and temporal variability that is different in relation to the season of survey and other factors (currents, winds, etc.). Maravelias (1999) showed a strong relationship between the kind of seabed substrate and herring distribution in the North Sea and this factor could be another source of variability could be in each geographical area.

Off the Spanish Atlantic coast, horse-mackerel and mainly blue-whiting make up large-sized schools which are generally found on the continental shelf (Meixide *et al.*, 1991; Carrera *et al.*, 2001). As a result only the Coruña schools showed a correlation between morphological and bathymetric variables which might be attributed to the presence of these two species.

School density or school energy or both factors together showed a very homogeneous pattern with bottom depth in all stocks. In all areas schools having the greater densities are located at shallower depths and in shallow waters. Scalabrin and Massé (1993) reported a similar relationship in the Bay of Biscay citing as a possible reason the differences in the distribution of sardine, the main species analysed, which is, in general, a coastal species with high energy values. However, in this study other species and areas have been included so that, in addition to specific variability, there must be other parameters, both physical and biological, that could have an impact on the relationships that all the stocks exhibited between the bathymetry and density or energy or both factors combined of the schools.

A joint analysis of all surveys from all geographical areas showed the existence of a strong common pattern in relation to school structure. Therefore, this pattern does not depend on factors such as species, biomass, latitude or longitude. Possibly, biological (sex, size, etc.) or behavioural (linked to reproduction, protection, feeding, etc.) aspects, among others, might be of great importance in school structure. Although there was an obvious tendency between the surveys of the same stock to group together their global disposition is difficult to explain. The spatial structuring of the surveys into geographical groups could be due to methodological differences, sampling, data extraction, etc., rather than to geographical factors (latitude, longitude), physical factors (bathymetry, temperature, etc.) or biological factors (species, size, biomass, etc.).

In general, only one morphological parameter, one energetic parameter and one (Aberdeen, Nantes, Heraklion) or two (Coruña, Sete, Palma) bathymetric parameters, according to geographical area, could characterize accurately the space-time distributions of the schools of each stock respectively. Similarly, the joint characterization of space-time distributions of the schools of all the stocks analysed would require only three parameters: a morphologic one, an energetic one and a bathymetric one. However, in other kinds of studies, such as the assignment of a species-school, a greater number and type of parameters will probably be needed. (Scalabrin *et al.*, 1996; Simmonds *et al.*, 1996).

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Annex (the STATIS method)

The STATIS method is an exploratory analysis that can be applied to quantitative data gathered from two different situations: (a) p observations on the same population (i.e. the same individuals over a time series); or, (b) p observations on different populations but measuring the same variables. The main objective of the method is to find a common structure, either for observations when the study is restricted to the same individuals over the time series, or for variables when different populations are concerned, which is called *intrastructure*. In this analysis, both situations occurred (i.e. different populations – survey areas – and time series), but the same variables were gathered. To apply the method, observations from the different areas are assumed to belong to the same Euclidean vectorial space.

For each school data set from each survey (n_t lines, p columns) the correlation matrix between the p school parameters is computed. For the whole data set (i.e. all the surveys) a series of correlation matrices are obtained, each noted V_t (t=1, . . . T). The compromise matrix is estimated by a weighted average of the V_t matrices.

A trace element S_{ij} is calculated as the scalar product between matrices V_i and V_j. With all scalar products S_{ij} a PCA is performed. Let τ_α and γ_α be the eigen value and eigen vector associated with factorial axis α. In the factorial space of S, the coordinate of matrix V_t on axis α will be: βα.

The PCA of V is then performed. The factorial space of V is used as the common space in which the matrices V_t are compared. A projection of each variable of each matrix V_t can be, therefore projected on the factorial space of V. Let μ_α and u_α be the eigen value and the eigen vector associated with the factorial axis α. The coordinates of the p variables of matrix V_t on the axis α are given by:

This enables us to draw the "trajectory" of a given parameter for all surveys t. The variability in the correlation structure in the series of matrices V_t was analysed by computing distances in the factorial plane of V between the positions of the point-variables. In comparison to the analysis in the factorial space of S, the factorial plane of V enables us to analyse the contribution of each variable in the variability of the correlation structure. In the factorial space of V, variable p_j has T positions (one for each matrix V_t), x_{jt}, around the mid point x_j representing the variable p_j in the compromise. Point c_{ja} is defined as being the centre point between points x_{jt} belonging to the same area. Then, the distances $dis(x_{ji}, x_j)$ are compared with $dist(x_{jta},c_{ja})$ to analyse whether surveys of a given area are closer together than from the compromise.

$$V = \sum_{t=1}^{T} \beta_t V_t$$

$$V\mu_\alpha\sqrt{\mu_\alpha} \sum_{t=1}^{T} \beta_t$$