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Standard protocols for the analysis of school based data from echo sounder surveys

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Abstract

This paper presents a set of standard extraction parameters and protocols for the use of image analysis techniques in the processing of echo sounder data. The paper includes parameters at the school, elementary distance sampling unit (EDSU) and regional levels. The school level parameters, which are mainly derived from the image analysis, fall into four main categories: positional, morphometric, energetic and environmental. At the sampling unit level (i.e. standard integration units, commonly 1 or 2.5 nautical miles), parameters used include: school structures, protocols for including layers and general scatter plus ancillary (e.g. environmental) variables. These variables are derived mostly from visual examination of the echogram and from ancillary data collected underway. Regional level parameters include those mapped from point samples (e.g. trawls) or which are available as maps. Each school thus has its own unique parameters and is associated with an EDSU and through that to regional data. We discuss the application of such databases to the analysis of echo surveys at a school level in relation to aggregation patterns (school, school cluster and population) and to changes in those aggregation patterns with stock biomass and exploitation pattern.

Keywords: Standard protocols; Schools; Acoustic surveys

1. Introduction

Ever since the introduction of acoustic methods for the quantification of fish biomass, there has been an interest in knowing what other sorts of information can be extracted from acoustic surveys. One of the most obvious is the study of the fish schools as seen in echograms. Data on the school's size, shape, structure, position and immediate environment can be extracted. These data can then be used, for instance, to give information on species composition or on the mesoscale distribution of the fish; the pattern of fish aggregation into schools and the clustering of those schools. Particularly important in the fisheries context is how aggregation patterns have changed historically in

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relation to stock level, exploitation pattern and the environment, and what impact these changes have on commercial fishing and assessment surveys. This approach is the subject of a current European Union (FAIR) research project entitled ''CLUSTER'' involving the present authors. To investigate these phenomena we have designed a protocol for the extraction of a standard database incorporating data on the school itself, its immediate surroundings and its wider context.

The most common approach to extracting data from echograms at the school level has been to use image processing algorithms or software applied to digital echogram data collected ping by ping and with the return signal from each ping collected in a number of depth bins. The data can then be treated as an ''image'' analogous to a visual image acquired using a frame grabber, each pixel in the image represents a single depth sample from a single ping. Again, a variety of approaches can be adopted to this process. The most common approaches are to analyse the data either ping by ping, or frame by frame, where a frame is made up of a number of pings. Detailed descriptions of these methodologies have been published elsewhere (Richards et al., 1991; Harabolous and Georgakarakos, 1993; Kieser et al., 1993; Reid and Simmonds, 1993; Diner et al., 1994; Scalabrin et al., 1996; Swartzman, 1997) and it is not our intention to examine the image processing methodologies here.

A number of papers have been published in recent years describing the results of the application of image processing to the extraction of school parameters. While in general these studies have used the type of algorithms described above they have involved the extraction of a wide variety of different school parameters. The type of parameter extracted from the image analysis process can be classified into four different groups:

- Positional — temporal, geographical and vertical (i.e. position in the water column).
- Morphometric — shape, etc.
- Energetic — total acoustic energy reflected and indices of internal school variation.
- Environmental — water depth, temperature, etc.

To place the extracted schools in their proper geographical and environmental context, it is also necessary to combine these school specific parameters with a range of appropriate biological and environmental parameters. In some cases these will be available in sufficient resolution to be applicable at the school level e.g. species composition of the school. In most cases this type of data will only be available at a coarser spatial resolution. The next level at which data is available is usually at the EDSU (elementary distance sampling unit) level. The EDSU is a distance over which the acoustic survey data are integrated to provide a single sample. In most cases this would be in the order of 1–5 nautical miles. We, therefore, propose that in addition to a database of schools and associated parameters, the researcher also produces an EDSU level database, containing information which is only available at this wider spatial scale, or which is more appropriate to collate at this scale. With cross referencing, the individual school can then be considered in the context of the appropriate EDSU. Further, some data are only available on a wider scale again, usually in the form of point or station data, or mapped and regional data sets. Examples of mapped data sets would include remote sensing data or seabed substrate maps. Using either mapped or gridded interpolated data it is then possible to cross reference the EDSU database to the wider spatial scale. This can be considered as a three-tier nested structure. Each school will have a set of unique associated parameters. It can be placed in the context of an EDSU, which will allow the inclusion of further (but no longer unique) parameters, which in turn are placed in the context of maps or gridded data at the third spatial scale.

The aim of this paper is to describe this process and the most appropriate set of parameters to extract. The school level parameters chosen can be described as primary parameters, i.e. they cannot be derived indirectly from any of the other parameters. These school level parameters will mostly be derived from an image processing type analysis. At the EDSU and mapped data levels the parameters will mostly be obtained from ancillary data sources.

The authors of this paper have been working in the field of image processing of echograms and relating these findings to the environment for some years (Harabolous and Georgakarakos, 1993; Reid and Simmonds, 1993; Diner et al., 1994; Masse et al., 1996; Scalabrin et al., 1996). The primary parameters described here have been chosen by the authors as being the most useful over a wide range of different aggregation patterns and as presenting a relatively simple extraction task.

2. Methods

We define three levels of data extraction:

1. The school level — parameters associated with each individual school, mostly derived from image processing of the echograms.
2. The EDSU level — where parameters are extracted over a fixed distance of the survey track, mostly derived from analysis (mostly manual) of the echogram as a whole, but including data from ancillary underway data collection, e.g. Thermosalinograph data (EDSU).
3. The region level — parameters which are only available in mapped form over large parts of the survey area, e.g. satellite temperature or sea colour data, or derived from point samples (trawl hauls or CTD stations).

Each level is appropriate for different types of data and all are relevant to the understanding of school typology and its relationship to its local and wider scale environment.

2.1. School level parameters

It is assumed that the echogram will be presented for analysis as a raster image with each pixel representing a single sample from a single ping. In the text we will henceforth refer to these as pixels. A pixel will have a standard set of properties defined by the performance of the system; ping rate, sampling rate, operating frequency and vessel speed. These properties are:

P_h the vertical dimension of a single sample. This is taken to be the time separation between adjacent samples (in ms) multiplied by the speed of sound in water (m ms^{-1}).

P_w the horizontal dimension of a single sample. This is taken as the distance travelled by the vessel between adjacent pings.

P_{csa} the cross-sectional area represented by a single sample ($P_h \times P_w$).

School level parameters fall into five general categories:

- Positional — temporal, geographical and vertical.
- Morphometric — shape, etc.
- energetic — total acoustic energy reflected and indices of internal school variation.
- Environmental — hydrographic and physical (seabed substrate and topography).
- Biological — species, age structure, other species, etc.

2.2. Positional parameters ($SP_{subscript}$)

The positional parameters are defined either in terms of latitude, longitude and date/time in the vertical plane or depth in the horizontal. On the echogram, each school is defined as having a vertical and a horizontal beginning (B_V and B_H) and end (E_V and E_H).

In the vertical plane, the beginning (B_V) is the first ping on which the school was detected and the end (E_V) is the last ping. Some echo sounders record data digitally, ping by ping, with each ping tagged with navigation data, usually from a GPS receiver. Alternatively, the position of a particular ping can be interpolated from whatever navigational data are available. The school position is defined as either the mean of date/time (SP_{time}), latitude (SP_{lat}), and longitude (SP_{lon}) of B_V and E_V or as the mean of the date/time, latitude, and longitude of all pings between B_V and E_V. The choice will depend on how much trust can be placed in the validity of the navigational stamp. The time is determined in the same way from the navigational data associated with each ping.

In the horizontal plane the beginning (B_H) is the shallowest depth sample in any ping in which the school was detected and the end (E_H) is the deepest sample. The horizontal school position (SP_{dep}) is defined as the mean of B_H and E_H.

2.3. Morphometric parameters ($SM_{subscript}$)

1. *School height* (SM_h). The distance (number of pixels$\times P_h$) between B_H and E_H expressed in meters.
2. *School width* (SM_w). The distance (number of pixels$\times P_w$) between B_v and E_v expressed in meters.

3. *School cross sectional area*(SM_{csa}). P_{csa} multiplied by the total number of pixels in the school (P_{tot}).
4. *Centre of rotation*. It has three values.
   4.1. Mean latitude of all samples in the school ($SM_{cr\text{-}lat}$)
   4.2. Mean longitude of all samples in the school ($SM_{cr\text{-}lon}$)
   4.3. Mean depth of all samples in the school ($SM_{cr\text{-}dep}$)

   While these are essentially positional parameters, they are included under morphometric because they are an expression of the deviation of the actual shape from an ideal circle.
5. *School perimeter* (SM_p): The perimeter of the school should be expressed in meters. It should be remembered that the pixels (i.e. the samples) have different vertical and horizontal dimensions (P_h and P_w). The image processing system used is expected to be able to produce an outline description. This will usually be a series of x and y co-ordinates of successive pixels around the perimeter of the school. The procedure should then be to define an algorithm to ''walk'' around the perimeter pixel by pixel. Choosing a starting pixel, the algorithm will then look for the next pixel, and calculate the x and y displacement to that pixel. If the displacement is in only one direction (x or y), the perimeter value is incremented by the appropriate value (P_h in the x axis and P_v in the y axis). If the displacement is in both directions (i.e. diagonal), the perimeter value should be incremented by

   $$\text{val} = \sqrt{(P_h^2 + P_v^2)}$$

   This procedure should then be continued for all perimeter pixels.
6. *Roughness of the school perimeter* (SM_r). This is expressed as the coefficient of variation (CV) of the distance in all directions between a perimeter sample and the centre of rotation. As in the perimeter value calculations, each distance should be calculated using the horizontal and vertical dimensions of the pixels (P_h and P_v) and the x and y displacement in pixels (P_x and P_y) between a perimeter sample and the centre of rotation is calculated using the relationship:

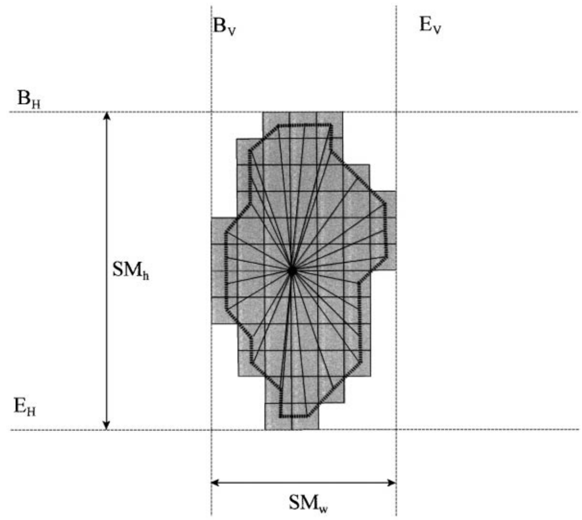


Fig. 1. Schematic representation of a typical school. B_H and E_H are the horizontal beginning and end. B_V and E_V are the vertical beginning and end. SM_h is the height and SM_w is the width. The dotted line is the perimeter as described in the text. The radial lines represent the distances from the geometric centre to all the perimeter pixels used to calculate the perimeter roughness.

$$\text{val} = \sqrt{((P_x \times P_h)^2 + (P_y \times P_v)^2)}$$

A schematic of these measurements is presented in Fig. 1.

2.4. Energetic parameters ($SE_{subscript}$)

1. *The total acoustic energy from the school* (SE_{tot}). It was calculated from

   $$SE_{tot} = \sum PE_i$$

   where PE_i is the energy from the ith pixel. All system calibrations should be applied prior to this stage.
2. *The average pixel energy value* (SE_{av}). It was calculated from

   $$SE_{av} = \sum \frac{PE_i}{P_{tot}}$$

3. *The variability in the pixel energy values within the school* (SE_{cv}). It was calculated as the CV.
4. *Centre of mass*. Again, as in the calculations for the centre of rotation, these parameters are

expressed as positional data (latitude, longitude, and depth of the school). These data can be compared to the positional data (SP_{lat},SP_{lon} and SP_{dep}) and to the centre of rotation data ($SM_{cr\text{-}lat}$, $SM_{cr\text{-}lon}$ and $SM_{cr\text{-}dep}$). The centre of mass is calculated as weighted average of the latitude, longitude, and depth of all the pixels in a school. The weighting is by the energy of each pixel relative to the total.

- Mean weighted latitude of all samples in the school ($SE_{cm\text{-}lat}$)
- Mean weighted longitude of all samples in the school ($SE_{cm\text{-}lon}$)
- Mean weighted depth of all samples in the school ($SE_{cm\text{-}dep}$)

$$SE_{pos} = \frac{\sum((PE_i/PE_{tot})100 \times PP_i)}{100}$$

where $SE_{cm\text{-}lat}$ is the mean weighted latitude of the school and PP_i the mean weighted latitude of the ith pixel.

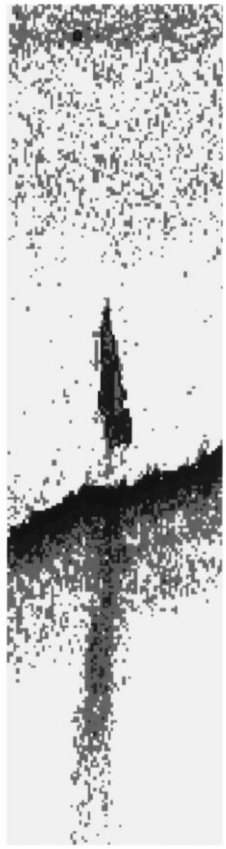
2.5. *School environment ($SD_{subscript}$)*

1. Minimum depth of the seabed under the school (SD_{min}).
2. Maximum depth of the seabed under the school (SD_{max}).

2.6. *Biological parameters*

Biological parameters cannot be extracted by the image analysis procedure. However, in many implementations, it is possible to tag individual schools as belonging to a particular species or species assemblage. This will depend on the information available to the researcher and his or her depth of understanding of the fish distribution and biology. Under special circumstances the researcher may also be able to tag schools as belonging to a particular age or length class of a species. The authors feel that, in general, biological parameters are best dealt with in this type of analysis at a wider spatial scale, either at EDSU or regional levels.

An example of the output from this analysis approach is presented in Fig. 2. The school itself (outlined in black) is shown on the left and the parameters extracted for this school are given in the table on the right. Some of the parameters are presented as pixels (x and y coordinates in the image) to allow direct comparison. In normal practice the horizontal values would be converted to latitude and longitude for archiving. Examples of the type of output for complete surveys are presented in Fig. 3. School databases were extracted for herring from four acoustic surveys in the northern North Sea, and the cumulative frequency distribution of four descriptors are presented here. A fuller analyses of these data is presented in Aukland and Reid (1998).



School Parameters

Species:	Herring
Date:	27-07-97
Time:	03:46
Latitude:	59° 25.6'N
Longitude:	3° 28.1'W
dB Threshold:	-60
Vertical start (pixels):	139
Vertical end (pixels):	187
Vertical start (m):	69.5
Vertical end (m):	93.5
Height:	24m
Horiz. Start (pixels):	625
Horiz. end (pixels):	636
Width (corrected):	112.55m
Area:	119.41m
Centre of rotation (Pixels - horiz.):	629.82
Centre of rotation (Pixels - vert.):	167.52
Perimeter:	253.1
Perimeter roughness:	46.04
Total energy V^2:	0.0247
Mean energy V:	2.07E-5
Pixel cv:	410.791
Centre of mass (Pixels - horiz.):	629.62
Centre of mass (Pixels - vert.):	168.99
Minimum depth:	102.2m
Maximum depth:	103.6m

Fig. 2. A single herring school from an acoustic survey identified in the image processing system. The table on the right gives the descriptors calculated for this school.

2.7. *EDSU level parameters*

The elementary distance sampling unit or EDSU is the distance (time) over which acoustic data are

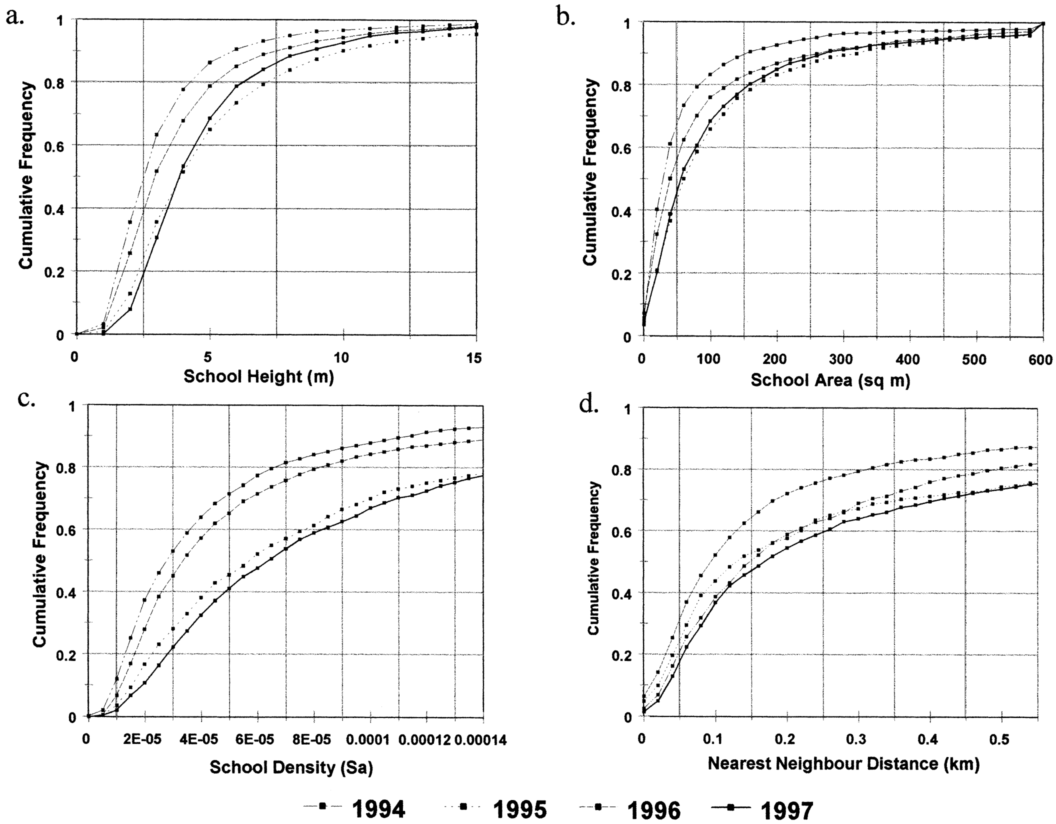


Fig. 3. Cumulative frequency distributions of: (a) school height; (b) school area; (c) school density and (d) nearest neighbour distance. The data are from four acoustic surveys in 1994–1997.

integrated to form a single sample (MacLennan and Simmonds, 1992). Many potential data sources which are difficult or impossible to express at the school level, may be better presented at the EDSU level. Each individual school can be easily associated with an EDSU by means of time, date and position.

Again these fall into a series of categories:

1. position,
2. energy,
3. hydrography,
4. acoustic typology,
5. seabed.

2.8. Positional parameters

1. Date and time: at the centre of the EDSU if possible.
2. Vessel log: number of elapsed miles along survey track at the centre of the EDSU if possible.
3. Latitude: at the centre of the EDSU if possible.
4. Longitude: at the centre of the EDSU if possible.

2.9. Energetic parameters

At the simplest level, this would be the total echo-integral for the whole water column across the EDSU. With some systems (e.g. SIMRAD EK500) it may be possible to divide the integral into sub-categories (e.g. the echo integrals from fish (either total or by species) or from plankton). It may also be possible to subdivide these into depth layers, e.g. the echo-integral from fish in a layer 100–200 m. The decision on how detailed such sub-categorisation should be will depend on the particular situation. As a minimum we would recom-

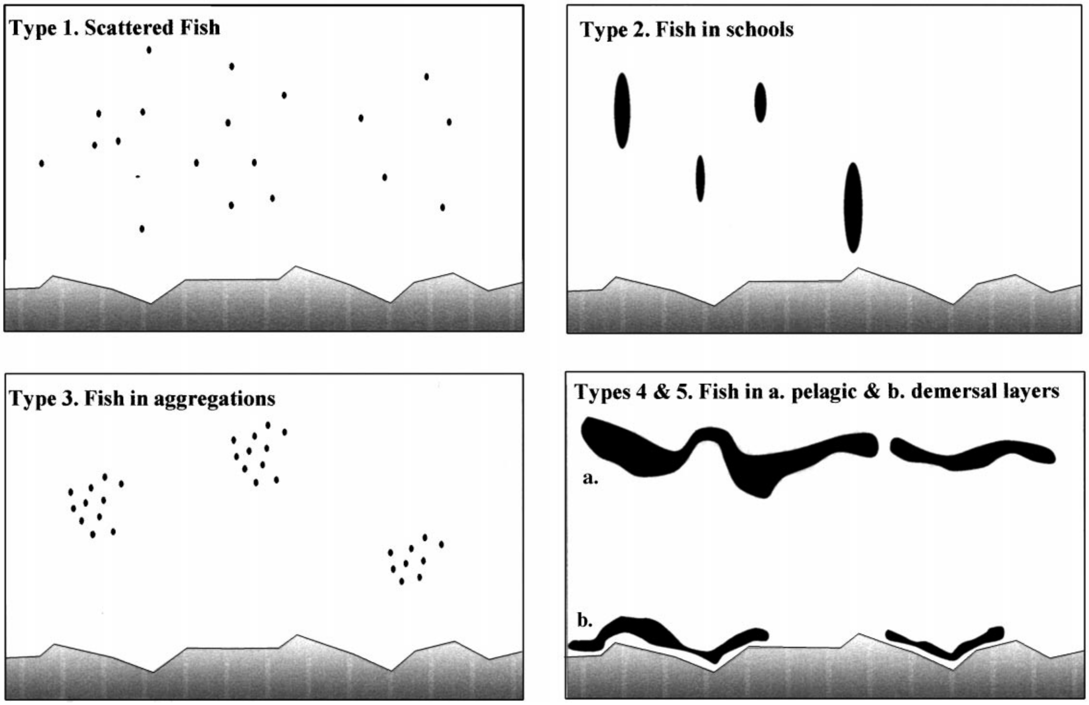


Fig. 4. Schematic representation of the acoustic typologies used for application to the EDSU database.

mend that a total integral subdivided between plankton and fish be included where possible. This should allow the comparison between schools from different areas dependent on the local fish or plankton backscatter.

2.10. Hydrographic parameters

Most research vessels will record sea surface temperatures and salinities (SST and SSS) under way during the survey. The mean SST and SSS should be recorded for each EDSU.

2.11. Acoustic typology

Many details of the fish distribution within an EDSU will be lost if the data acquisition is restricted to only those schools, which are picked up and retained by the image analysis process. Some aggregation patterns will also not be amenable to image processing systems, e.g. long continuous layers. We would recommend that the EDSU be assigned a typology dependent on the behaviour of the fish aggregations within it. This addresses the question of how the immediate surroundings relate to the patterns of the fish aggregations (e.g. do schools behave differently when "alone" than when in "clusters?"). These would fall into six categories (see Fig. 4), recorded as a binary presence or absence factor:

1. *Scattered fish*. EDSU characterized by large numbers of single fish echoes where the fish are not aggregated into structures.
2. *Fish in schools*. EDSU characterised by a number of discrete and identifiable schools. This information can come direct from the school database described above. Instead of a binary factor this could be recorded as the number of schools in that particular EDSU.
3. *Fish in aggregations*. In some echograms fish can be seen to form into loose aggregations, which are difficult or impossible to define using the IA approach. These are often diffused and of a fairly low energy level and with pixel S_v values close to the recording threshold. Such aggregations are often described as "clouds".

4. *Fish in pelagic layers*. These are often fairly dense layers of fish in mid-water which can continue for many miles. Such layers are difficult to describe using frame/image based IA systems. There are often apparent small breaks in such layers. We feel that such structures, even if they can be handled as a series of separate schools are best seen as a layer structure. In this context it should be remembered that the echogram is effectively a slice through the water column. A layer, even if it has occasional breaks, is probably best represented in three dimensions as more like a pancake with occasional holes through it. The breaks do not represent separations between discrete groups but thinner, less dense, areas of the overall structure.
5. *Fish in demersal layers*. These can be considered as similar to the pelagic layers but occur close to or in contact with the seabed. The same arguments about spatial continuity hold for demersal as for pelagic layers.
6. *Other*. We have attempted to define the major aggregation patterns experienced by this group of authors; however, it is inevitable that other patterns exist and they should be incorporated in this part of the database.

2.12. Seabed parameters

The topography of the seabed is well known to have an important effect on the local spatial distribution of fish, particularly demersal or semi-demersal species. The EDSU can be characterized in a number of ways:

1. *Water depth*. Expressed as the average depth of the seabed in the EDSU. Where the echo sounder is able to record the depth ping by ping, this should be the average of these values across the whole EDSU. Where such data are not available, this value could be manually assigned based on visual examination of the echogram.
2. *Topography of the seabed*. This is an expression of how variable the seabed appears in this particular EDSU. We have defined four categories:
   - Flat: generally continuous, with little or no change.
   - Undulating: characterized by relatively small changes over the EDSU.
   - Bumpy: characterized by more marked changes over the EDSU.
   - Spikes: characterized by rapid and dramatic changes in depth over the EDSU.

These descriptions are obviously highly subjective. We have restricted the descriptions to four categories for this reason. The first and last represent the extremes, and the other two represent the transitional state. If depth data are available on a ping basis, it would be possible to include a CV value of the seabed depth as a more objective seabed roughness parameter. However, compensation for heave and roll due to weather would need to be incorporated in this calculation.

3. *Slope of the seabed*. This is a subjective parameter, and so we have opted for three categories: flat, medium, and steep. These should be defined in terms of the range of slopes encountered during the surveys to be studied. In combination with the roughness parameter, this should adequately express a useful range of different types of seabed.
4. *Seabed substrate*. A number of acoustic instrumentation packages are now available to allow remote seabed substrate discrimination (e.g. RoxAnn (Chivers et al., 1990, Schagintweit, 1993)). Alternatively, visual examination of the echogram is often sufficient for the experienced user to determine if the seabed is soft or hard (i.e. mud or rock). Based on experience in both domains we would recommend four substrate categories: soft (muds, clays and sands), medium (gravels and small stones), and hard (boulders and rock). Additionally, a mixed category should be included where more than one of these types occurs within one EDSU. Again without a well groundtruthed discrimination system, this will be a subjective interpretation, but should still prove valuable.

2.13. Strata or regionalized parameters

Some data, which may be important in the understanding of fish aggregative behaviour will only be available in a regional or strata form, not at the school or EDSU level. The most obvious examples would be biological data derived from trawl hauls during the survey (e.g. species assemblage, age or length frequencies). These are effectively point data, but can be interpolated to give maps over the entire survey area. Other point sample data, which may be interpolated over the entire survey area, include plankton tows and CTD (conductivity, temperature and depth) stations. Other parameters, such as satellite derived data on SST or sea colour will only be available in a synoptic mapped format. In all such cases, the requirement is to be able to give each EDSU a value based on such mapped or point data.

There are two methods for handling such data. In the first, the data can be reduced to a series of strata. For example, CTD data might be used to define three types of hydrographic stratum: mixed waters, frontal zones and stratified waters, based on presence and type of thermocline. Each EDSU could then be assigned to one of these three strata. Alternatively the data could be transformed to a grid using a commercial software package such as SURFER (Golden Software, CO, USA). This grid could then be used as a look-up-table from the EDSU file. Each EDSU could be assigned the value at the nearest node on the grid.

The data sets, which we feel are most important in the study of fish assemblage patterns are:

1. Biological, derived from trawl hauls: presence or absence of common species, age and length compositions and maturity state.
2. Biological, derived from plankton tows: presence or absence and abundance of major food or indicator species/taxa.
3. Hydrographic, derived from CTD stations: presence/absence, depth and gradient of thermocline and presence/absence of major water types defined from TS profiles.
4. Hydrographic, derived from satellite data: SST and ocean colour.
5. Metorological, derived from vessel log or weather service maps. Occasionally this type of data may be available at the EDSU level.
6. Anthropogenic: fishing activity and exploitation information.
7. Seabed substrate: derived from hydrographic service maps.

3. Discussion

The aim of the present paper is to provide users and potential users of image processing systems for application to echogram data with a standard framework, which should allow a direct comparison of results from different species and situations. The aim is definitely not to constrain innovation in the field. The image processing technology and/or software used and the application of specific algorithms are deliberately not covered here. The potential user can either design his or her own algorithms and programmes or can build an application based on commercially available software packages. There is a wide range of appropriate packages available, and trial versions are often available over the World Wide Web.

The parameters we have described here are not exclusive. At the school level, we have chosen a restricted set of parameters. The choice was made to provide as wide a range of descriptors as possible (i.e. covering as many aspects of the school as possible), while avoiding those, which were likely to be correlated. Ease of extraction and calculation was also a criterion. In our experience to-date, usable school descriptors are largely restricted to shape and energy plus positional parameters. Furthermore, there is a strong tendency for parameters within these categories to be strongly correlated. So, a wider school will also tend to be taller and have a greater area and perimeter. It will also tend to have a more complex shape. This conclusion is borne out by analyses of school descriptors using principle component analysis (PCA) — (for an example see, Nero et al. (1990)). The first component is generally a collection of morphometric criteria, and the second a collection of energetic criteria. Within each of these general categories it is possible to define a range of descriptors from simple to complex. Simple descriptors include; height, length, area, etc. and total, mean and peak energy. Complex shape descriptors include fractal dimension (Nero et al., 1990; Harabolous and Georgakarakos, 1993) and perimeter roughness. Essentially, these descriptors are designed to parameterise shape further than simple dimensional descriptors (height, width, etc.). Complex energetic descriptors include; pixel CV, acoustic roughness, kurtosis, skewness, standardized peak to trough distance (SPT) and mean distance between voltage peaks (PP) (Rose and Leggett, 1988; Nero and Magnuson, 1989; Nero et al., 1990). These descriptors are designed to parameterise the internal structure of the school. The purpose of this paper was to provide a standard and simple set of descriptors to allow comparison between data sets. We have chosen perimeter roughness and pixel cv, but it seems probable that all these parameters will adequately describe shape and structure complexity, and we do not intend to imply any judgement on other possible choices. The main difficulty with these complex descriptors is that they are all likely to work well with large schools (e.g. Fig. 3) but are likely to become increasingly invalid with smaller schools. In the studies illustrated in Fig. 4, 85% of the schools were made up of five samples or less, making the use of complex descriptors problematic.

At the EDSU and regional level, we chose those parameters, which have been shown to have an effect on the distribution and behaviour of some species.

There are two main research applications for the type of school database described in this paper; species identification and the study of aggregation patterns. For the purpose of species identification it is assumed that particular species will display a specific range of schooling behaviour patterns which are characteristic and diagnostic. This approach has been examined by Rose and Leggett (1988), Nero and Magnuson (1989), Nero et al. (1990), Richards et al. (1991), Reid and Simmonds (1993), Harabolous and Georgakarakos (1993), Diner et al. (1994) and Barange (1994). While some success has been achieved, particularly where only a few species are involved (Richards et al., 1991), there can also be considerable difficulties (Scalabrin et al., 1996). The second main application is for the study of fish aggregation patterns themselves. In this approach the fish schools are assigned to species (where possible) based on trawl hauls the operators experience. The main interest is then in how the schools themselves vary under different oceanographic, biological or anthrophogenic scenarios. Examples of this type of approach include relationships to seabed topography (Richards et al., 1991); spatial and temporal variability (Scalabrin and Masse, 1993); relationships to environmental parameters (Swartzman et al., 1995; Swartzman, 1997); variation according to species present (Masse et al., 1996); and variations with time of day and water depth (Petitgas and Levenez, 1996). The impact of commercial exploitation activities on aggregative behaviour has not been well documented, however, see Potier et al. (1997). There are numerous anecdotal reports of fish schools being broken up by fishing and remaining so for some time afterwards. Some anecdotal evidence suggests that fish schools of a particular species are chronically smaller and more scattered in areas of high exploitation as compared to adjacent, less exploited areas.

In addition to well as the structures, positions, etc. of the schools, it is important to consider how the schools themselves aggregate or cluster in space, and how this, in turn, is affected by external parameters. There are good arguments to suggest that clusters can be seen as the functional level of fish aggregation as schools can break and coalesce, but clusters may stay together for longer periods (Petitgas and Levenez, 1996; Swartzman, 1997). An important aspect, from the point of view of fisheries management, is the relationship between aggregation patterns and the state of the stock at both the school and the cluster levels. As a particular stock increases or decreases, one would expect concomitant changes in the fish distribution and aggregation patterns. McCall (1990) has proposed the ‘‘basin’’ effect, where fish would concentrate in preferred areas at low stock levels and spread out as the stock increases. This raises the question of what, if any, effects occur at the smaller spatial scales. Do schools become smaller or further apart at lower stock sizes, or does the ‘‘basin’’ effect mean that the aggregation patterns stay the same but over a narrower area? These questions have implications for both commercial fishing activity and for assessment surveys, as catchability (i.e. chance of encounter) will depend on the aggregation patterns. This topic is the subject of a current European Union research programme involving the authors, and it is hoped to be able to report some of the findings in the near future.

In the image processing parts of this paper we have considered only the extraction of school shape and energy parameters from the echograms as they have been collected. It is important to understand that the image as seen on the echogram is not a true representation of the actual school. Firstly, the image is best considered as a two-dimensional slice through a particular school, and not the whole school. However, given a reasonable number of sampled schools, it is reasonable to assume that we have a representation of the variability in size, shape, etc. of the real population of schools. Additionally, this slice is likely to cut across the school away from its centre. This would tend to bias the observed school dimensions, giving smaller widths and heights than the actual school. It is possible to apply a correction for this bias, given that the schools are assumed to be cylindrical (Reid and Simmonds, 1993). The second main problem lies in the acoustic instrumentation used to observe the schools. Each sample (or pixel on the image) is derived from a volume of water and not a point. This sample volume will increase with depth as the beam spreads. This has the effect of making a school appear wider on the echogram the deeper it is observed (Reid and Simmonds, 1993). In turn, the scale of this bias will depend on the volume backscattering strength (S_V) of the observed school. The higher the S_V the wider the effective beam angle of the transducer. Bias corrections for this have been suggested by Reid and Simmonds (1993) and Kieser et al. (1993). A further problem lies in the threshold values chosen by the operator to analyse and view the echogram. Many echosounder systems e.g. SIMRAD EK500 can collect samples down to a value of -100 dB. Clearly what is seen by an image processing system as a school will depend on the threshold chosen, the lower the threshold the larger the perceived school. It is not our intention to examine these questions here, however, it is important to understand that the observed characteristics of fish schools on echograms have inherent biases due to the system design. Simulation and modelling studies are currently being carried out within the context of the EU programme mentioned above, and, again, it is hoped to be able to report some of the findings in the near future.

The final question to be addressed is ‘‘what is a school?’’. This is a topic of intense debate both among behavioural biologists as well as those working with acoustic data. We believe that it is impossible to resolve. For the purposes of this type of study we have chosen to define the ‘‘acoustic school’’. This is not necessarily the real school, but is the representation of that assemblage as seen on the echo sounder. The best definition we have seen was given by Kieser et al. (1993) as ‘‘an acoustically unresolved, multiple fish aggregation’’.

Given the problems described above, the question must arise as to how useful shape, size and energy parameters are when extracted from digitised echogram data. The answer to this question largely depends on the questions the researcher wishes to ask. The parameter values collected will contain substantial and currently unknown biases: however, it is our view that they can still be regarded as reasonable correlates of the genuine school values. Provided that the equipment, system settings, and image analysis parameters are kept constant, and that appropriate steps are taken to reduce the known biases, we believe that useful information can be derived on the variability of aggregation behaviour. If the researcher wishes to draw inferences about the exact dimensions of fish schools, then the data should be treated with caution.

In conclusion, this paper presents a proposed standard approach to the extraction of fish school descriptors from acoustic survey data. These standard protocols are primarily intended as a guide for new workers in the field and to allow existing workers to directly compare their results. Much of the work in this field has been directed at the identification of aggregation to species/species assemblage in the context of a specific survey series or situation, where comparison to other studies is relatively unimportant. We feel that the potential gains in the understanding of fish aggregative behaviour in the wild from being able to compare results from different species and different environments are enormous and explicitly require such a standardised approach.

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