Fisheries Technology Committee

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REPORT OF THE

STUDY GROUP ON ECHO TRACE CLASSIFICATION

La Coruna, Spain
18–20 April 1998

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1. OPENING OF THE MEETING

The meeting was chaired by D. Reid, R Aukland was appointed rapporteur. A full list of participants is attached

2. BACKGROUND

The terms of reference for SGETC as agreed at the FAST meeting (Woods Hole, USA, 1996) and approved at the ICES Annual Conference, Reykjavik, Iceland, September 1996 were:

Address and document aspects of fish aggregation, distribution and classification including:

i. Methods of classifying echo traces
ii. Comparison of the performance of these methods
iii. The effect of fish behaviour on the precision of classification
iv. The scope for integrating existing research programmes

The study group will report to the April 1998 meeting of WGFAST and to the Fish Capture Committee at the 1998 Annual Science Conference

2.2 The general background to this study group was presented in the report of the first meeting of the SGETC in Hamburg, 15-17 April 1997.

3. ORGANISATION OF THE MEETING

The meeting was organised to allow the presentation of draft sections of the report, consideration of these and the discussion and implementation of follow on work for the completion of the final report. The sections agreed for the report and the section collators are given below.

A. Appropriate school descriptors (D. Reid)
B. Single and Multi-Beam Sonar (F. Gerlotto)
C. Wide band & Multi frequency sounders (DN MacLennan)
D. Post Analysis procedures (G Swartzman)
E. Data visualisation and analysis software (A Castellon)
F. Data exchange formats (I McQuinn)
G. Model simulations to provide beam correction parameters (N. Diner)
H. Comparison of analysis methods (D Reid)

Additionally, the meeting included the results of an echogram scrutiny workshop held at the Herring Survey Planning Group in Bergen, Norway, January 1998.

3.1 Standard Set of Appropriate Descriptors for Echo Trace Classification

A draft report on appropriate descriptors for echo trace classification was presented by D Reid. The descriptors were defined at three levels of resolution: school level, ESDU (Elementary Sampling Distance Unit) level and regional level - see Appendix 1

While the protocols proposed for the descriptors were generally accepted, this presentation led to a general discussion revisiting the concept of «what is a school». It was agreed, as in previous discussions, that no exact definition of a school was possible, as it would vary from situation to situation.. It was agreed that the parameters used for identifying a school in any particular situation (but not their minimum values) should always be height, width and energy. The chosen values should be regarded as the definition of a school in that particular situation ONLY and these definition criteria and the acquisition/analysis threshold should be an explicit part of the presentation of any analysis.

It was recognised that the acoustic image could not be regarded as a picture of the true school due to the intrinsic limitations of the acquisition equipment (see section 3.7). In this context it was also recognised that no rigorous definition existed of a biological school. It was agreed that given these conditions the acoustic image could be regarded as directly related to the aggregative behaviour of the fish. Some aggregation patterns such as layers or continuous aggregations along contour lines (esp. Shelf break aggregations) cannot be defined in the same simple, height and width terms as single discrete schools. They would tend to have multiple values for these parameters as well as e.g. for depth. The ESDU level parameter acquisition proposed allows the inclusion of layers in any analysis. However, continuous aggregations along contours are not generally prone to characterisation in the context of a transect based survey. The study of such aggregation should be regarded as a special case and treated separately. In his context it was recognised that most of the data sets available would be from assessment driven, transect surveys carried out with vertical echosounders, and were not directed studies of school structures *per se*. The descriptors defined here should be generally applicable for both directed school studies and for the future use of multi beam instruments (see Appendix 2) allowing the extension of school parameter acquisition to include a third dimension for the schools.

3.2. Single and Multi-Beam Sonar

This presentation constituted a review of the existing knowledge and State-of-the-art for the application of sonar technology to the study of echo traces (see Appendix 2). The presentation included an introduction defining the history of these approaches and the terminology. The draft included sections on single beam sonars, multi-beam horizontal sonars, side scanning, multi-beam sonars and a section on the future development of sonar. Each section included a consideration of the methodology, its application in echo trace research, it's limitations and its potential future uses.

It was agreed that the draft was highly useful and appropriate for inclusion in the final report largely as it stands. F Gerlotto will complete the text in collaboration with E Simmonds, O Misund and S. Georgakarakos for incorporation into the final report.

3.3. Wide band & Multi frequency Sounders

At the first meeting of the SGETC it was agreed that the report should include the state-of-the-art on the application of wide band & multi frequency sounders. This section was to be coordinated by D MacLennan. Present and past workers in this field were contacted and asked to complete a questionnaire on their activities. Fourteen replies were received and the collated results were presented to the meeting by D MacLennan see Appendix 3.

It was agreed that the work in this field was still experimental but that it may have great potential in the future. D MacLennan, in collaboration with A Brierley & V Holliday, agreed to develop the draft report presented at this meeting for inclusion in the final report

3.4. Post Analysis Procedures

At the previous meeting of the SGETC it was agreed that the report should include a section on the current post-processing methodologies used in the community of the analysis of parameters derived from the analysis of acoustic survey data. The methodologies and the person identified to write each section were as follows:

Point processes (P Petitgas & M Soria)
Geostatistics (P Fernandes)
Generalized Additive Models and clustering techniques (G Swartzman)
Neural Networks (S Georgakarakos & J Harabolous)
Discriminant Analysis (A Brierley)
Bayesian Approaches (C. Scalabrin, Y Simard & G Swartzman)

At the present meeting it was agreed that this list should also include categorical analysis and P Petitgas agreed to produce a section on this. Submissions were prepared on all but the Bayesian approaches. However, it was agree that the drafts were generally not well enough developed for general presentation. It was agreed that the chairman would liaise with the authors to complete the sub-sections in a suitable form for inclusion in the final report. It was agreed that each sub-section should follow the following format:

- A brief general description of the methodology with key references
- A description of its advantages and application to fisheries and particularly echo trace classification studies, with key references
- A description of its limitations

These will be collated by the chairman and an overview prepared in consultation with the authors.

3.5. Data Visualisation and Analysis Software

It was recognised at the previous meeting that a wide variety of data visualisation and analysis software was in use in the community and that it would be of great use to know what these were and what they did. To this end a questionnaire was prepared and circulated to all groups known to have or to be developing such software. A Castellon presented the collated results of this process and these findings are presented in Appendix 4.

Nineteen responses were received to the questionnaire. Additionally one further contribution was identified at this meeting. The results have been tabulated and organised to present the characteristics of each system. The intention here is not to present an analysis of the relative quality of each system but to allow the reader of the report to be aware of what has been done to date and how to find out more if required.

It was agreed that this compilation would be valuable to anyone planning to develop such software themselves or who wished to acquire such software. A Castellon agreed to obtain details of the system identified at this meeting and to incorporate this into a completed section for the final report.

3.6 Data Exchange Formats

It was agreed at the previous SGETC meeting that a critical factor in the development of research in echo trace classification was a the development of a common data exchange format. The need for this is highlighted in section 3.8 below. It was agreed that the development of such a format lay outside the scope of this study group, and that it is a highly complex and difficult discipline in itself. Furthermore, it was known that such a format was being developed by the Canadian Department of Fisheries and Oceans.

I McQuinn presented the current state of development of the Canadian system. The format is based around the use of data tuples held in a newly developed .hac file format. A fuller description of this system is to be prepared by I McQuinn for inclusion in the final report. It was noted by the group that this format was being implemented in the latest versions of the IFREMER analysis software MOVIES+. It was agreed that this format looked very promising as it incorporated many of the required elements, was freely adaptable and contained good provision for future proofing. While it is not the role of this SG to endorse such a format, it was agreed that this design would be very useful to the purposes of this group and that the use of this format should be explored for the exchange of acoustic survey data, particularly with reference to studies on the comparability of different analysis systems (see section 3.8 below). It was felt that an examination of the .hac file format for this exercise would be a useful pilot study prior to any decision for a more formal adoption by the wider acoustic community

3.7 Model Simulations to Provide Beam Correction Parameters

It was agreed at the previous SGETC meeting that an important problem in the development of the study of echo traces (schools) using acoustic survey data was the absence of suitable algorithms for the correction of the perceived shape and energy of a school for distortions introduced by the sounder beam pattern. N Diner & C Scalabrin were asked to examine the possibility of developing such algorithms and to report on these at the present meeting of SGETC. N Diner presented a comprehensive and scholarly study on this matter (see Appendix 5). It was concluded that it was possible to make corrections to the perceived horizontal dimensions and to the volume back scattering strength of the school.

3.8 Comparison of Analysis Methods

It was agreed at the first meeting of SGETC that it was important to be able to compare the performance of the different software analysis procedures for echo trace descriptor acquisition which are currently extant. To this end it was agreed that a data file exchange and analysis exercise should be set up. Each of the active groups would attempt to identify the «objects» in each of the data sets and to extract the standard set of descriptors (see 3.1) for those schools. The aim of his exercise was to allow comparison of the acquired descriptors from analysis systems which implement different algorithms directed at the same ultimate objective. Inter system differences lie both in details of algorithm and in differences of approach. The most important of these is between the «image» based approaches e.g. MLA and the «ping» based approaches. The exchange was set up and images collated by R Aukland at Marine Laboratory, Aberdeen & B. Lundgren at DIFTA. These were then circulated to the various groups active in his field. It was found that there were insuperable difficulties in converting image data between analysis platforms. This was despite the substantial amount of work put into standardisation and common archiving prior to the data being sent to the groups. As a result it proved impossible to complete a meaningful analysis of the differences between these systems. This was despite the substantial amount of work put into standardisation and common archiving prior to the data being sent to the groups. The group acknowledges this effort, mainly by R Aukland and B Lundgren, and would like to emphasise that the subsequent problems are not a reflection on them.

It was recognised that this problem highlighted the lack of a suitable data exchange format for acoustic survey data. The definition of data exchange formats were included in the work of the SG, and to this end the group examined the work being carried out on this subject by the Canadian DFO (See 3.5). Given the absence of any other well documented standard format, and given that the Canadian .hac format has already been adopted by some of the institutes involved in this study, it was agreed that this was a suitable, interim, exchange format to allow the comparison exercise to be carried out in the near future. All the active groups agreed to determine if this format could be implemented on their systems and if possible to do so, before the next FAST meeting. As a consequence, it will not be possible to include the results of any tests of the relative performance of the different systems in the completed study group report. It was agreed that if the implementation of the .hac file data exchange format was successful for these systems, that a workshop should be held thereafter to test the relative performances of these systems.

It was agreed that a qualitative and quantitative analysis of the relative performance of the various systems remained of prime importance. It was also agreed that the differences lay nit simply in system performance, but in the perception of the operator as to «what is a school» in different situation. To this end it was proposed that a workshop should be held to examine these questions. It is suggested that the workshop cover two separate aspects of the echo trace classification procedure. At the first level, the operators should work on data sets which are provided without any additional information. This can be regarded as a «blind» experiment and will test the performance of the operators in defining «what is a school» in a variety of different situations. At the second level the operators will be required to extract the descriptors from a defined subset of the schools in the provided data sets. The precise extraction criteria e.g. energy threshold, will be defined for each data set.

A presentation was made by P Petitgas on some comparative exercises carried out within the EU project CLUSTER which was reported on at the previous SGETC meeting. These covered two main areas. The first was an examination of the impact of using different energy thresholds in the analysis stage. Attention was focussed on the suitability of the use of a -60 dB threshold value. Such a threshold is in standard use in analysis systems such as MOVIES+, and has been proposed by C Scalabrin as a suitable optimum threshold given that the schools being studied have a volume back scattering strength in the region of -40 to -45 dB. The outcome of the studies, mostly based on work done at MLA and at IFREMER was that the value of -60 dB was suitable. It should be emphasised that this conclusion applies ONLY to the specific situations examined. However, it was agreed that an analysis threshold 15 dB less than the mean school volume back scattering strength was a valuable guide for the application of such systems.

It was agreed that the operators of the existing echo trace classification systems, should each prepare a document describing the system and it's methodology, with an appreciation of its abilities and limitations. These will be collated by the chairman who will also provide an overview which compares and contrasts these systems.

3.9. Results of the «Scrutiny» Workshop

A major aspect the of debate on «what is a school» was addressed at an echogram scrutiny workshop held in Bergen January 1998. «Scrutiny» is that element of the analysis of an echogram where the operator decides which echotraces in the echogram are the species of interest. In many cases this means that the operator is deciding which of the echotraces are the schools of the species of interest. This question is regularly debated in any forum where the topic of echo trace classification is raised. It was therefore felt that the results of the workshop were relevant to the work of SGETC. The workshop involved a number of teams making independent choices as to what were the schools in a series of echograms from a number of different surveys. The results were then collated to illustrate the level of agreement between the different operators. The important message from this analysis was that, given appropriate trawl data, experienced but naive operators generally identified the same schools as being of the species of interest. A copy of the report from this workshop is presented as Appendix 6

It was noted that the exercise covered data sets from a restricted geographical area. was directed at only one species and was conducted in the context of a stock assessment survey, and not specifically school acquisition. It should be noted that the circumstances of the study represented a worst case scenario, as the scrutiny was by naive operators and in these surveys in general 80-90% of the aggregations containing the species of interest would have been trawled on, and better informed decisions generally taken. In the discussion it was pointed out that the analysis might have been more appropriate if the deviations between the analysis teams had been considered as representing a bias and not a variance. This will be considered prior to the report being presented in completed form. It was agreed that while some of the findings of this report were important to the work of the SGETC, it was not appropriate to include it in the final document.

4. RECOMMENDATIONS

4.1. It was agreed that considerable progress had been made in most areas of the SGETC remit. It is recommended that the SGETC continue by correspondence. It was agreed that all completed draft sections be sent to the chairman by 30th November 1998 at the latest. The chairman will then collate these and circulate the completed document to all authors. It is recommended that there be a final editorial meeting under the chairmanship of Dr. D. Reid during the FAST meeting in St Johns, Canada in April 1999. This meeting will be solely for editorial purposes and will not be an open meeting as was the case with previous SGETC meetings. The chairman agreed to circulate all contributors in May and September, to remind them of their responsibilities!

4.2. The group recommended that the terms of reference remained unaltered. The SGETC will report to the April 1999 meeting of the WGFAST and to the Fishing Technology Committee at the 1999 Annual Science Conference.

5. CLOSURE OF THE MEETING

5.1. The chairman thanked the hosts, Instituto Espanol Oceanografico - A Coruna and particularly Pablo Carerra for his support and enormous effort. The chairman also thanked the participants for their efforts and for the enthusiastic participation in the meeting.

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Appendix 1

Standard Protocols for the analysis of school based data from echosounder 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 the school, sampling unit (ESDU) 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 ESDU 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 & population) and to changes in those aggregation patterns with stock bimass and exploitation pattern.

INTRODUCTION

Ever since the introduction of acoustic methods for the quantification of fish biomass there has been an interest in 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 can then be used, for instance, to give information on species make up 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 relation to stock level, exploitation pattern and the environment, and what impact this has 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 transmission by transmission and with the return signal from each transmission 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" representing a single depth sample from a single transmission. Again a variety of approaches can be adopted to this process. The most common approaches are to analyse the data either transmission by transmission, or frame by frame, where a frame is made up of a number of transmissions. Detailed descriptions of these methodologies have been published elsewhere (Richards et al 1991; Harabolous & Georgakarakos 1993; Reid & 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 4 different groups;

- Positional - temporal, geographical and vertical (i.e. position in the water column)
- Morphometric - shape etc
- energetic - total energy returned and indices of internal school variation
- environmental - water depth

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 ESDU (Elementary Sampling Distance Unit) level. This 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 here that, in addition to a database of schools and associated parameters, the researcher also produce an ESDU 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 ESDU. Further, some data are only available on a wider scale again, usually in the form of point or station data, or mapped data sets - 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 ESDU database to the wider spatial scale. This can be considered as a 3-tier nested structure. Each school will have a set of unique associated parameters. It can be placed in the context of an ESDU which will allow the inclusion of further (but no longer unique) parameters which in turn is placed in the context of maps or gridded data at the third spatial scale.

The aim of the present 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 ESDU and mapped data levels the parameters will mostly be obtained from ancillary data sources.

The authors of the present paper have been working in the field of image processing of echograms and relating these findings to the environment for some years (Harabolous & Georgakarakos 1993; Reid & Simmonds 1993; Diner et al 1994; Scalabrin et al 1996; Masse 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.

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 ESDU 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 under weigh data collection e.g. Thermosalinograph data (ESDU - Elementary Sampling Distance Unit)
3. The region level - parameters which are only available in mapped from over large parts of the survey area, e.g. satellite temperature or sea colour data, or derived from point samples e.g. 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.

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 transmission. In the text we will henceforward refer to these as pixels. A pixel will have a standard set of properties defined by the performance of the system; transmission rate, sampling rate, operating frequency and vessel speed. These are:

P_h The vertical dimension of a single sample. This is taken to be the time separation between adjacent samples (in milliseconds) 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 transmissions.

P_{csa} The cross-sectional area of a single sample ($P_h * P_w$).

School level parameters fall into five general categories:

- Positional - temporal, geographical and vertical
- Morphometric - shape etc
- energetic - total energy returned and indices of internal school variation
- environmental - hydrographic and physical (seabed substrate and topography)
- biological - species, age structure, other species etc.

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 & B_H) and end (E_V & E_H).

In the vertical plane, the beginning (B_V) is the first transmission on which the school was detected and the end (E_V) is the last transmission. Some echosounders record data digitally, transmission by transmission, with each transmission tagged with navigation data, usually from a GPS navigator system. Alternatively, the position of a particular transmission can be interpolated from whatever navigational data is 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 & E_V or as the mean of the date/time, latitude and longitude of all transmissions *between* B_V & 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 transmission.

In the horizontal plane the beginning (B_H) is the shallowest depth sample in any transmission 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.

Morphometric parameters ($SM_{subscript}$)

1. School Height (SM_h): The distance (number of pixels * P_h) between B_H and E_H expressed in meters.
2. School Width (SM_w): The distance (number of pixels * 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: Three values:-
   i. Mean latitude of all samples in the school (SM_{cr-lat})
   ii. Mean longitude of all samples in the school (SM_{cr-lon})
   iii. Mean depth of all samples in the school (SM_{cr-dep})

   While these are essentially positional parameters, they are included under morphometric as 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 & 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 & y coordinates 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:

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

   This should then be continued for all perimeter pixels.

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, using the relationship:

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

Energetic parameters ($SE_{subscript}$)

1. The total acoustic energy from the school (SE_{tot}) : Calculated from:

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

where: PE_i The energy (voltage squared) from the ith pixel.

2. The average pixel energy value (SE_{av}): Calculated from:

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

3. The variability in the pixel energy values within the school SE_{cv}: 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} & SP_{dep}) and to the centre of rotation data (SM_{cr-lat}, SM_{cr-lon} and SM_{cr-dep}). The centre of mass is calculated as weighted average of the latitude, longitudes and depths 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-lat})
Mean weighted longitude of all samples in the school	(SE_{cm-lon})
Mean weighted depth of all samples in the school	(Se_{cm-dep})

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

where:

SE_{pos} = the mean weighted latitude, longitude or depth of the school
PP_{is} = the mean weighted latitude, longitude or depth of the ith pixel

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})

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 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 ESDU or regional levels.

ESDU level parameters

The elementary sampling distance unit or ESDU is the distance (time) over which acoustic data are integrated to form a single sample (Maclennan & Simmonds 1993). Many potential data sources which are difficult or impossible to express at the school level, may be better presented at the ESDU level. Each individual school can be easily associated with an ESDU 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. Sea Bed

Positional parameters

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

Energetic parameters

At the simplest level this would be the total echo-integral for the whole water column across the ESDU. 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 plankton. It may also be possible to sub-divide these into depth layers e.g. the echo-integral from fish in a layer 100-200m. The decision on how detailed such sub-categorisation should be will depend on the particular situation. As a minimum we would recommend 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 biomass.

Hydrographic parameters

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

Acoustic typology

Many details of the fish distribution within an ESDU 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 ESDU 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 aggregation patterns of fish, e.g. do schools behave differently when "alone" than when in clusters. These would fall into 6 categories, each recorded as a presence or absence, binary, factor:

1. Scattered fish: ESDU characterised by large numbers of single fish echoes where the fish are not aggregated into structures
2. Fish in schools: ESDU 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 ESDU
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 diffuse 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 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.

Sea bed 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 ESDU can be characterised in a number of ways:

1. Water depth: Expressed as the average depth of the the seabed in the ESDU. Where the echosounder is able to record the depth transmission by transmission, this should be the average of these values across the whole ESDU. Where such data is not available this value could be manually assigned based on visual examination of the echogram.
2. Roughness of the seabed: This is an expression of how variable the seabed appears in this particular ESDU. We have defined four categories:

Flat:	Generally continuous - with little or no change
Undulating:	Characterised by relatively small changes over the ESDU
Bumpy:	Characterised by more marked changes over the ESDU
Spikes:	Characterised by rapid and dramatic changes in depth over the ESDU

   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 the transitional state. If depth data are available on a transmission basis it would be possible to include a CV value of the seabed depth as a more objective seabed roughness parameter.
3. Slope of the seabed: Again 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 & Burns 1987, Schlagintweit 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 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 ESDU. Again without a well groundtruthed discrimination system, this will be a subjective interpretation, but should still prove valuable.

Strata or regionalised 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 ESDU 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. Plankton tows and CTD (conductivity, temperature & depth) station or vessel log book data on weather (wind speed/direction and sea state) data have similar characteristics. Other parameters such as satellite derived data on SST or sea colour will only be available in a mapped format. In all such cases, the requirement is to be able to give each ESDU 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 ESDU 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, Colorado, USA). This grid could then be used as a look-up-table, from the ESDU file. Each ESDU 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, 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. Meterological, derived from vessel log or weather service maps. Occasionally this type of data may be available at the ESDU level.
6. Anthropogenic: Fishing activity and exploitation information
7. Seabed substrate, derived from hydrographic service maps.

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 image processing technology and/or software used is deliberately not covered here. The potential user can either design their 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 all inclusive. 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. At the ESDU 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 Richards et al (1991), Reid & Simmonds (1993), Harabolous & 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 and the operators experience. The main interest is then in how the schools themselves vary under different oceanographic, biological or anthropogenic scenarios. Examples of this type of approach include; relationships to seabed topography (Richards et al 1991); spatial and temporal variability (Scalabrin & 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 & 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.

As 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 effected 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 & 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 it's 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 & 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 & 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 & 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 -100dB. 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 question 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 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 echosounder. 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.

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Appendix 2

FAST W.G., La Coruña, Spain, 18*23 April 1998-07-08 Study Group on Echo trace classification (SGETC)

DRAFT, not to be cited
without prior referrence to the authors

CURRENT STATE OF THE ART OF SONAR TECHNIQUES

by

F. Gerlotto, O. Misund, E.J. Simmonds, S. Georgakarakos

This document is prepared in order to document the recommendation of SGETC, Hamburg, April 1997, where :

> « *The other approach which had been used was through the use of single and multi-beam sonar. Although there are still difficulties in understanding how such systems operate because of signal processing characteristics present in the system but not described in equipment documentation, the group agreed that much useful information could be gained from this equipment. F Gerlotto, in conjunction with O Misund, S Georgakarakos and J Simmonds agreed to prepare a draft report for the next meeting of the SGETC on the current state of the art of sonar techniques and their future development for inclusion in the final report.* »

INTRODUCTION

It exists several synthesis on sonar studies, where sonar is a part or totality of the work. We may cite SIMRAD (1964), Forbes and Nakken (1972), Mitson (1984), MacLennan and Simmonds (1992), Diner and Marchand (1995) , Misund (1997), among others. The objective of this paper is not to describe the theory and technics used for sonar research, but to explore the past, present and future use of these tools for fisheries research. For any question concerning theory and technical topics, we refer to these synthesis.

The term SONAR (acronym for Sound Navigation and Ranging) is nowadays rather confusing, and a redefinition could be proposed for this report.

Let us consider that Sonar is the proper name for ***any underwater active acoustic device which is not a vertical echo sounder (i.e. single beam[1] deployed on a vertical axis).*** If such a definition is accepted, sonar can be one of the following acoustic devices :

⇒ single beam directed in a non vertical direction ;

[1] In this definition, the split-beam and dual beam transducers are considered as single beam.

⇒ multibeam, whatever their main direction (considering that a multibeam is not directed exclusively along a vertical axis).

Inside this family we will only consider the tools used for fisheries acoustics. We will not take into account those pieces of equipment which are studying plankton at high frequencies although they fit in the above mentioned definition. Nor will we consider in details the state-of-the-art of non conventional tools, such as Continuous Transmission Frequency Modulated Sonar (CTFM) or non linear acoustics. Acoustic tags will not be described neither.

As in the case of the echo sounder, the sonar was not specifically designed for scientific research, but for professional (fisheries, oil extraction, harbour management, etc.). The potential use of sonar for research was considered once fishermen were using it currently. But the « scientific sonar » still does not exist, contrarily to the echo sounder. As far as research is concerned, the history of sonar is rather similar to that for fishing activities

The first sonars were single beam horizontal. This began with the use of military sonars after the second world war. We may cite a paragraph of Simrad (1964) for its historical interest : « *Mr Einar Lea, consultant to the Norwegian State Department of Fisheries (..) contacted the first allied naval vessel which arrived at Bergen, Norway, in May 1945. They informed him that not only could fish be detected by means of sonar but in a number of cases corvettes or submarines chasers had mistakenly attacked schools of fish for submarines(...) ..the corvette Eglantine was placed at Mr Lea's disposal during the winter herring fisheries of 1947* ». These tools were used in fisheries research, and the most important effort aiming to take the data into account are likely those of FAO team in Morocco, and US team in California, in the late 70s. Nevertheless it seems that single beam horizontal sonar did not give all the results that were expected, for several reasons.

After single beam, the following tool to be used was the multibeam horizontal sonar. This tool is first described in the fisheries research literature by two « historical » papers from Rusby (1977) and Cushing (1977) who described the horizontal shape of herring schools. The problem at this time was the huge effort required for processing the data, and the multibeam horizontal sonar was not considered as applicable to fisheries research during more than one decade.

The following step was the use of omnidirectional horizontal sonars, which were designed for fishermen. These tools are rather similar to multibeam, with that difference that they attempt to give a complete view of the 360° around the vessel. This system was designed first through the use of a multibeam sonar observing successively large sectors (e.g. 6 beams of 6°, see Bodholt and Olsen, 1977), then by true omnidirectional, with simultaneous 360° observation. These tools are much more recent and appeared during the mid 80s in the fisheries. They were used in fisheries research but gave few results at the beginning (Diner and Masse, 1987 ; Misund, 1987), and their use did not become as universal as it could be expected, until the interest of such a tool for behavioural research and stock abundance estimate be proved by the work of the Norwegian at the end of the 80s (Misund, 1996).

Another use of multibeam sonar was the development of side scanning sonars. We may cite the paper of Harden Jones and McCartney (1962) describing such a tool. The first one applied on fish schools was the G.L.O.R.I.A. system designed in UK in the early 70s (Rusby et al, 1973). This kind of tool was not specifically designed for fisheries but for bottom mapping. It had a great success and an important number of systems exists in the world. The scanning sonar is a multibeam sonar used in a vertical plan perpendicular to the vessel direction. It allows to describe precisely the three-dimension relief of the bottom. Its use for fisheries research is more recent than the other : after very preliminar suggestion by Rusby et al (1973) and more detailed work by Gunderson et al (1984), its interest was clearly demonstrated by Ona and Eger (1987), but the first application of side scanning sonar for fisheries acoustics at real scale was done in 1993 (Gerlotto et al, 1996).

The last use of multibeam sonar is as « multibeam echosounders ». In this case the sonar is deployed on a vertical plan as in the case of side scanning sonar, but the main axis of the sonar plan is vertical too. The main difference is that the sonar does not present necessarily a wider scanning beam than most of single beam echo sounders (i.e. around 30°). Their main interest compared to single beam echo sounder is that they allow to give a detailed description of the fish location below the vessel and very close to the bottom (Allais and Person, 1990 ; Diner and Marchand, 1995).

Sonars present a number of limiting factors when applied for fisheries research, that will be presented below. Nevertheless they may take advantage of the real-time computation capabilities and they are certainly now the next step of fisheries acoustics development.

This paper will describe each one of these tools, their application in the field of fisheries research, their limitations and their future.

1. SINGLE BEAM SONAR

1.1. Application in fisheries research

1.1.1. School counting. The main use of the single beam horizontal sonar (S.H.S.) was first to count fish schools over an area on the side of the vessel. The methodology is described by Vestnes (1964) and Forbes and Nakken (1972). Some more detailed information is provided by Smith (1970). The general principle is to set the sonar horizontally on the side of the vessel and to scan the lateral area of the transect (fig.). Then an optimal zone is defined within which the fish schools are counted and measured. This zone is limited by two lines : one close to the vessel corresponds approximately to the distance where the water column is supposed to be exhaustively insonified, and where the effect of the vessel on the fish behaviour is assumed null. The far line corresponds either to the maximum range of the sonar or to the efficient range, where discrimination between the school echo and background noise of bottom echoes is still possible. The most usual range is from 200 to 500 meters (Smith, 1970). Since the work presented by Lamboeuf et al (1984) on sardine survey off Morocco, no more papers were published, which indicates that this method is not used anymore.
1.1.2. School behaviour. This kind of research was not the most important, but gave some pionner results on school avoidance. The best example is the work of Neproshin (1974), who described the determinism of school avoidance in relation with the hour of the day, the noise of the vessel (speed), etc. (fig.).
1.1.3. individual fish studies. Another application of single beam horizontal sonar was to apply it on a fixed location in order to evaluate the abundance of migrating fish. This method was first used for salmon counting . It became recently of wider use due to application of horizontal acoustics in shallow waters (Trevorrow, 1997 ; Thorne, 1997 ; Duncan and Kubecka, 1993 ; Kubecka et al, 1994 ; Guillard, in press ; Gonzalez and Gerlotto, in press). The main difference between these two approaches is that fixed horizontal is usually of smaller range and is focused on single fish more than on schools.

1.2. Limitations

1.2.1. Sampling variability. Evidently all the sources of error of any acoustic device (particularly echo sounder) apply in the case of sonar, and it is not worth detailing them here. Hewitt et al (1976) list the main sources of variability, among which the target size (i.e. the horizontal dimension of the school) is likely the most important. The origin of the error on school size is not different from echo sounder error when observing a school vertically, but is more dramatic considering the range of observation. The case of small schools is also documented by Hewitt et al (1976), who conclude to a general underestimate of small schools. Another source of variability is the TS of a single fish or school. This point is critical in any cases, for the following main reasons :

- single fish : the side aspect of the target and its huge variability makes the TS measurement extremely variable. Some measurements were presented by Kubecka and Duncan (1995). Differences of more than 30 dB can be observed according to the position of the fish in the beam (Kubecka, 1993) (fig.).
- single fish and schools : the multiple reflection of sound on the surface and the bottom makes it difficult to know precisely the incident energy on the target. In some favourable cases, the distance between the target and the surface and the bottom allows to extract the reflected echoes from the direct echo (Trevorrow, 1995), but when the target is far from the transducer and close to the surface or the bottom, such a discrimination is impossible (fig.).
- schools : the school is not often completely included inside the beam, and the actual TS of the school has to be reconstructed.

1.2.2. sampling volume. Calculation of the sampling volume in the case of horizontal single beam sonar is practically impossible, due to multiple reflection both on the bottom and the surface, and to the changes in the beam directivity due to hydrology. The usual way is to consider that due to the long distances the water column is exhaustively sampled at some distance from the vessel.

1.2.3.. Effect of hydrological characteristics. The hydrological characteristics of the sea are usually highly anisotropic, with a strong vertical stratification. This fact is overcome by vertical echo sounders which cross the strata perpendicularly, but is important in horizontal acoustics (fig.). A good image of this impact is given by Rusby et al (1973). This may result to blind areas at large distances from the vessel. Moreeover the changes of hydrological conditions and the long range may have a rather important effect on the on sound absorption values and correction

1.2.4. Impact of bottom echoes. The sonar range is much longer than the depth, and echoes from the bottom are often observed on the sonar echogram. When the bottom is flat this gives a continuous line, easy to recognise. When the bottom is rough, some echoes may appear and are practically identical to school echoes (fig). The other problem related to echoes far from the vessel is the multiple reflectivity on bottom and surface. This point makes difficult the precise evaluation of a school TS and in some part the measurement of the horizontal dimensions of a school.

1.2.5. Choice of settings. Considering that single beam horizontal sonar is applied mainly on fish schools, none of the usual TVG settings is theoretically applicable. The best potential setting would be 30 log R, which is supposed to take into account the fact that the school does not transmit the reflected energy in all directions. Nevertheless this point is mainly theoretical and as far as fisheries acoustics is concerned, no detailed work was done and the linearity of echo energy related to distance is not clearly described.

1.3. Future of single beam sonar

Single beam horizontal sonar was used for school counting during the 70s mainly, and was abandoned later on. The main reason of such a situation is that it was extremely difficult to discriminate between school echoes and echoes from other targets (bottom mainly) and to evaluate the sampled volume, therefore the correlation between the abundance estimates from vertical echosounding and sonar was extremely low. We may consider that single beam horizontal sonar is not used anymore for school observation. Moreover the technology has dramatically improved with the introduction of multibeam sonar making SHS methods for school counting obsolete.

Nevertheless this method has reappeared recently for shallow water observation of scattered fish. A Seminar was held in London in 1995 and a special issue of Fisheries Research on this theme will be published soon on these developments. Technics have improved on this field, by the availability of elliptic transducers, which allow a wider volume to be sampled with no (or low) incidence of surface or bottom.

Considering scattered fish at short distances, the main points to be studied are :

- the TS values for side aspect of fish ;
- the effect of reflections on surface and bottom ;
- the problem related to side lobe reflection
- the significance of echoes of big fish at short distance (i.e. what is the meaning of a piece of fish inside the beam ?). This point is not specific to horizontal single beam sonar, but is critical in this case.
- the significance of targets recorded close to the nearfield.

2. MULTIBEAM HORIZONTAL SONAR

We will consider here both multibeam sonar and omnidirectional sonar, although there is one important difference : multibeam sonar needs to scan the total area step by step instead of giving a simultaneous overview of the 360° field. Therefore some time variability in the data can appear.

2.1. Application in fisheries research

Multibeam horizontal sonar (MHS) was applied to fisheries very soon after being conceived. The first papers concerning this point are those from Bodholt and Olsen (1977) who used a 36° (six beam of 6° each) scanning transducer. This tool was connected to computer facilities which allowed to display underwater situations (fig). This equipment was designed for fishermen, but the potential use for behaviour studies was described by the authors. Another important paper was published at the same period by Cushing (1977) on the use of multibeam for describing the internal structure of fish schools. No other work was done on this field before the late 80s (fig). These first papers demonstrated very early the potential use of multibeam horizontal research for school studies. We may list 4 fields of research where MHS is applied.

2.1.1. School counting. This is the first potential application. School counting is not very different from the school counting methods developed for single beam, and the limitations are basically similar, although several filters and adaptation improve the results (bottom recognition, noise filters, use of CTFM, etc.). As MHS appeared after the limitation on the use of single beam for fish counting being described, and considering that the new tool did not bring any substantial improvement on these limiting factors, practically no important work was published on this topic. This application of MHS is marginal in fisheries acoustics.

2.1.2. School biomass and geometry. The first obvious interest of MHS is that the actual horizontal dimensions of a school can be measured. Taking advantage of this capability, Misund (1990) presented an exhaustive list of the geometrical dimension of a school as observed by sonar and the correction factors to be applied (fig). Applying this method Misund et al (1991) measured the relationship between school geometry and biomass, by comparing the results of sonar and echo sounder data. Nevertheless some results are contradictory. In the above mentioned paper, the authors conclude « *Our investigation demonstrate that relationships exist, which enable conversion from sonar-measured school dimensions to school biomass* » and recommend to improve the methodology by using narrow beam, rather high frequency sonars. In other publications, this relationship does not seem so clear, for two reasons. The first one is the huge variability of school shape : Freon et al (1992), using aerial views of a single school showed that a school can change its horizontal surface by a factor 4 in less that 10 minutes, due to behavioural conditions. The second point is the variability of school density as observed by echo sounder. Misund (1991), Freon et al (1991) showed that the school density is highly heterogeneous and subject to strong changes according to fish reaction to the environment. Therefore the measurement of school biomass using MHS is still considered as valuable but with a rather high variance, and requires of some behavioural measurements and knowledge before to be applied systematically. Misund (1993) concludes : « *the predictability of school biomass based on the single measurement of the area of a recorded school is affected with substantial uncertainty* » and suggests some improvements on the methodology, mainly through the use of narrow beam sonar and algorithms for automatic detection. According to the author, one of the main interests of using multibeam horizontal sonar for school biomass estimates is that all the schools are observed, including those close to the surface, which is not the case with vertical echo sounding.

2.1.3. mapping. This capability can be considered at two scales. The first one is at large scale and continuous along a transect. The position and number of schools inside a surface centred along a transect are measured, which gives an idea of the number of school per surface unit for each ESDU. This method is not very different from school counting, but the fact that multibeam is used allows to obtain a more accurate description of type school distribution than a single beam could give. The other method is to measure the distances between schools inside a single image or on a given surface. This study may give some information on the 2D clustering behaviour of the schools (Soria et al, 1997). This kind of work is just beginning and very few work have been published.

2.1.4. School behaviour. This point is certainly the most interesting improvement to fisheries acoustics that multibeam horizontal sonar brought. The school behaviour was first considered by Bodholt and Olsen (1977), but the most important works in this field are those from the Institute of Marine Research of Bergen, Norway, wince the late 80s (Misund, 1987). Using multibeam sonar allows to obtain information on several characteristics of school behaviour :

- school swimming behaviour : the school speed and direction can be measured on the screen and calculated (Bodholt and Olsen, 1977 ; Misund, 1987, 1990 ; Misund and Aglen, 1991, etc.) (fig). The impact of this behaviour on fisheries research and models of fish behaviour including school movements and reaction were described by several authors, taking advantage of these observations (Pitcher et al, 1997 ; Soria et al, 1997 ; Misund and Aglen, 1991, etc. (fig).

* school reaction to a vessel : the avoidance behaviour of fish school was observed by Diner and Masse (1987), Misund (1990), Misund and Aglen (1991), Engas et al (1991). Goncharov et al (1989) studied jack mackerel school avoidance. The authors cite similar results obtained by Lisovoy (1973) on *Sardinella* (probably using single beam horizontal).
* adaptation of fisheries and research activities to school behaviour. Misund et al (1991) describe the potential impact of changes in the purse seine design on catchability of schools, as observed by multibeam sonar.

2.2. Limitations

2.2.1. applicability to research. The first limiting factor is that practically no MHS is designed specifically for research. Most of the features (gains, settings, etc.) are adapted to fisheries purposes. The filters allow to give a good idea of the « ideal » school to be captured, and removes all the other echoes. Therefore the use of standard MHS is affected with high risks of error when considering school number (Brehmer and Gerlotto, 1997). Another drawback is that no adapted calibration procedure exists for sonar signal when applied to fisheries research.

2.2.2. Data collection and processing. The main problem is the huge amount of data to be collected and stored : two methods exist. The first one is to collect screen images through video recording. This method is certainly the most common, as it is a cheap and easy-to-operate method. Most of the MHS offer a video output and recording data does not present any problem. The counterpart of this method is that a part of the information is lost (due to the rather low definition of the video image in pixels compared to the original acoustic signal), and that processing the data is not easy : automatic schools image recognition and extraction from the video images is complicated, as schools do not present any particular shape, dimension or energy making them different from other echoes. The second method is to develop specific software to collect directly the acoustic information. This is certainly the best method, but it still present limitation, due to the quantity of data. Processing the data is generally done by eye on video images, but can be performed using specific software. Very few work were done on this topic (Misund, 1997). In both cases, the limiting factor is the school image recognition.

2.2.3. School recognition. The geometry of the school echoes inside the beams is not easy to describe. According to the hydrological condition, areas may be under- or over-sampled Under some conditions, echoes from surface or bottom may interfere. Schools are not always easy to discriminate from the noise, apart the big dense schools which remain a long time in the sonar range. For smaller schools, or for those which appear only during a short time, discrimination is mainly a term of personal experience of the operator. More generally, in MHS studies the scientist must have a good experience of sonar before to be able to recognise accurately schools on a MHS screen. This is also well known by fishermen (or by the Navies) : not everybody is able to interpretate properly sonar images.

2.2.3. Significance of the data. The main problem is the relationship of the actual horizontal dimension of a school and the image of the echo on the screen. The dimensions of this image may be affected by the echo energy, the side lobes, the position of the school in the beams, etc. This is particularly dramatic with wide beams and low frequencies (Misund, 1993). Another problem, related to the former one is the precision of school counting : in some cases, the noise is too high to allow a correct counting of schools.

2.3. Future of multibeam horizontal sonar

There is no doubt that MHS will continue to play an important role in fisheries acoustics in the near future. The acoustic devices are improving constantly, and the automatic school recognition capabilities of the MHS is an important field of research for the designers. The main interest of these tools is that they are able to observer schools at large distances, and on a large area, sampled instantaneously, thus to give a good view of schools under natural conditions (i.e. not perturbed by a vessel). This point allows to have a good knowledge of the clustering behaviour of schools. The study of clusters began in the mid 90s (Swartzmann, 1994 ; Petitgas et al, 1996 ; etc.) and demonstrated that important results could be expected in this area, which could enhance the understanding of spatial strategy of fish stocks in relation with exploitation. This field is certainly one of the most interesting new areas of research and MHS will be certainly the favourite tool for measuring these parameters, once the limitation due to school recognition overcome. The main fields of research on MHS could be the following :

- School image recognition. This point is critical, and should be undertaken with different objectives as are considered at present : the objective would not be to recognise the best « fishable » school, but to observe all the schools in a given area, whatever their dimension and behaviour. Filters should be slightly different.
- Calibration procedure. At the moment it exists practically no calibration methodology for MHS. Therefore these tools can only give a rough idea of school geometry. A proper calibration should be conceived.
- Study of school clustering. The occupation of space by schools is an important characteristics, that will be studied in part using MHS (see the works of SGETC).
- School behaviour (avoidance). Here too, MHS is one of the few tools able to give an evaluation of the bias due to avoidance, and offer correction factors for vertical echo sounding.

3. SIDE SCANNING SONAR

As detailed above, Side scanning sonar (S.S.S.) is the most recent tool introduced in fisheries research, although its potential use was described a long time ago (Gunderson et al, 1984). As far as we know, only two teams are working on the development of this methodology : an european team (inside E.C. FAIR Project AVITIS) and a Canadian team (Melvin, comm. Pers.). We will describe more in detail the European method. The sonar employed is covering a total receiving beam angle of 90° with 60 beams of 1.5° each (transmit beam: 100°), and 15° in the perpendicular direction (at -3 dB point). The sonar operating frequency is 455 kHz (bandwidth 20 kHz) with a pulse length 0.06 ms. The conventional output consists of video images, reconstructed from the 60 beams to produce a real time observation (fig). These are recorded during the survey on videotapes for post-processing in the laboratory. Ion this case, the post-processing is either by eye, to produce a database containing the main geometric data; or by digitisation using an image analysis software. The second output is the digital data provided by the sonar. For each ping a matrix of 60 columns (representing the 60 beams) and 2040 lines (i.e. 122400 pixels) is generated. At the moment this kind of information is not easy to collect, due to the enormous amount of data (approximately 50 Mb per min). Once these raw digital data are extracted, it becomes possible to reconstruct the 2D and 3D images, with a much better definition than when using the video image. Processing beyond this point is similar for both the digital and digitised data sets. The sonar scans the side of the vessel route, and exhaustively explores the water volume (fig.). When used as profiling sonar (90° starboard), the third dimension is obtained through the succession of pings along a transect, as in conventional vertical echo sounding (Gerlotto et al. 1994). During the surveys, the sonar head is directed at 45° downside, which allows to scan from the vertical (underneath the boat) to the horizontal (parallel to the sea surface) on one side of the vessel. The range is fixed at 100 meters, and the image is a smoothing of 2 or 4 successive pings (Soria et al. 1996). The canadian system is not very different from the european one : the sonar is 180° instead of 90, the frequency is lower (200 kHz ?).

3.1. Application in fisheries research

3.1.1. School counting This application is not fundamentally different from the school counting method developed for single beam. Fish schools are counted all along the vessel road, from the vessel up to the maximum « efficient » range (in case of european S.S.S., 80 meters in a total range of 100). The main difference is that there is no risk of confounding school echoes with bottom echoes, as the bottom is clearly observed on the images. Therefore counting is normally unbiased, as the water volume is exhaustively observed and schools are clearly identified. These two characteristics resolve the most critical points that were stressed in SHS, and we may assume that school counting is able to give now practical information.

3.1.2. School dimensions. The SSS allows the vertical and horizontal dimensions and position of the schools be measured (fig.). This gives the possibility to reconstruct precisely the 3D school shape.

3.1.3. School behaviour. 3D acoustics, by the way of observation at different horizontal distances from the boat, allows for the calculation of a correction factor for vertical echo sounding, as in the case of MHS ; but the fact that the vertical dimension is also exhaustively observed allows a more detailed analysis. Soria et al. (1996) show that the effect of the vessel on school distribution can be demonstrated and evaluated. Soria et al. (1996) propose a general avoidance model. We present here the results obtained during five surveys. The figure 6 shows the spatial distribution of all the fish schools along the side of the vessel, which demonstrate the existence of an avoidance reaction. Contrarily to the MHS, the behaviour studies are not dynamic (it is impossible to measure the speed and individual reaction of the schools), but statistic. This shows that the two tools are complementary :

MHS describe the instantaneous reaction of a given school, while SSS describe the effect of school behaviour on survey data.

3.1.4. Biomass estimate. Simmonds et al. (1992) showed that the accuracy of the biomass estimates depended on methodological and sampling errors and on a series of biases. The 3D sonar method seems to be in condition to improve the precision of the biomass estimate in these two domains: it increases the sampled volume, which could improve the precision of the estimate, and it allows to count the schools far from the boat, which eliminates the bias due to lateral avoidance. The echo energy of the school is theoretically measured too, but in this case not all the schools can be measured, due to the high background noise generated by side lobes at distances above the vertical distance to the bottom : background noise can be as strong as the school echo.

3.1.5. Shallow water observation. We described in paragraph 1.1.3. the recent development of SHS for shallow waters. This tool present one important drawback in the case of shallow waters : reflectivity on bottom and surface may have a strong influence on the results, first because the meaning of a single fish echo is not clear, second because it is difficult to discriminate between bottom or surface echo and fish echo. SSS is a good answer to this problem, as bottom and surface are precisely located and fish echoes easily discriminated (Gerlotto et al, 1998) (fig.). Distribution of school and single fish can be recorded, and fish biomass evaluated with less biases than when using SHS.

3.1.6. Multibeam vertical echo sounder. We described in the beginning of this document the possibility of using multibeam sonar as vertical echo sounders. This methods is rather similar to the use of SSS as described above, with the difference that the axis of the observed plan is vertical. This tool reduces dramatically the problems related to the beam angle : fish close to the bottom can be observed with a good precision, as well as fish at long distances (fig.). (Diner and Marchand, 1995).

3.2. Limitations

Most of them are rather similar to the MHS limitation. Some others are specific.

3.2.1. Technical limitations. The most important limitation in SSS is the effect of side lobes. The bottom echo is extremely strong compared to school echoes, and is producing noise on all the beams (fig.). This limitation has two consequences. The first one is that the information at farther distances than the depth is contaminated by background noise. Echo energy cannot be taken into consideration. Fortunately this phenomenon does not affect seriously the school image, as far as geometry and shape are concerned. This implies that we cannot consider school biomass for the schools at distances above the depth distance. The second point is that it is practically impossible to consider the use of SSS for scattered fish, except under particular condition. This may have an impact on shallow water experiments.

3.2.2. Calibration. This point is not very different from the case of MHS. Some wxork are undertaken, which will soon produce a calibration procedure for the SSS employed by the European team.

3.2.3. Data management. The huge amount of data collected by SSS makes an acquisition and storage procedure indispensable. We calculated that the volume of data to be recorded is around 50 Mb per minute. Very critical at present, one may assume that the improvements of data processing and storage capabilities of PC will give a positive solution to this limitation.

3.3. Future of side scanning sonar.

There is no doubt that SSS will be an important tool in the future of fisheries acoustics, as it resolves several problems present in other tools, as described above. We may imagine that the future SSS will observe the complete plan (180°, from one side of the vessel to the other) with120 to 180 beams of 1.5 to 1.0° ; the beams around the vertical axis (e.g. the 10 or 20 beams closest to the vertical axis) could give echo integration results, as in this water volume fish are observed in a standard position and side lobe has no impact), and the other beams would give information on the school number and shape, and allow a better extrapolation of the echo sounder results. This tool would allow to consider the avoidance factor as overcome.

4. FUTURE TECHNOLOGICAL DEVELOPMENT OF SONAR SYSTEMS

4.1. Technology of multibeam sonars.

Two points require still some research : the effect of side lobes in SSS, and the school recognition in MHS.

4.1.1. Side lobe effect. We detailed the effect of side lobes. As long as this problem is not resolved, SSS will not present important improvement compared to vertical echo sounder for biomass estimates. The ideal equipment would present at least a difference of 40 dB between main lobe and side lobe, which is far from the usual case (around 20-25 dB). Once such a tool developed, we may assume that SSS would be in condition to substitute the vertical single beam echo sounder for fish stock assessment, considering all the advantages SSS presents compared to echo sounder.

4.1.2. School echo recognition. At present the filters are developed for fishermen. Most of the small schools are not taken into consideration. The school image is presented according to fishermen's wishes, and do not necessarily represent true dimension, except on some tools (Misund). A proper algorithm for school recognition should be developed. Once this « scientific filter » developed, MHS will allow to evaluate correctly the school clustering behaviour and the average avoidance reactions.

4.2. Processing.

4.2.1. Data acquisition and storage. There is usually no way to access the signal itself (either analogical or digital), and the main output for most sonars is the video image. This is not satisfactorily for scientific purposes, as the scientist cannot define what are the effects of the different settings, and have no evident possibility for calibrating the beams. Moreover the data are usually not so detailed as the initial signal is. There is a high loss of definition. Some specific methods for acquisition and data storage have to be developed.

4.2.2. Image analysis. Sonars generally give 2D or 3D images. It is clear that image analysis will be the only processing method for these data. Some works have been achieved, for specific purposes. Nevertheless there is there a wide field of technical research to be developed in order to make sonar data analysis possible.

4.2.3. Data analysis. The research using multibeam sonars are still preliminary, and the actual capability of those tools are not completely explored. It seems clear, for instance, that spatial analysis tools could be applied, as sonars give 2D maps of school structures and distribution. The use of geostatistics inside cluster images, or even school images, could be considered (fig.). Also, school typology could be enhanced by the use of 3D reconstructed schools.

4.3. The future tool.

One may imagine the ideal future acoustic tool for fish stock research : it would have a multibeam architecture, not very different from that one already proposed by several designer (fig.), i.e. the following features :

- a 360° multibeam head fir the horizontal plan, rather low frequency, beams as narrow as possible (3° ?), for horizontal observation of schools dynamics and distribution ;
- a 180° multibeam head for the vertical plan, applied perpendicularly to the vessel road, observing exhaustively the water column from one side of the vessel to the other. Very narrow beams (around 1°), rather high frequency.
- Inside the 180° beams, a portion (around 30°) centred on the vertical line below the vessel processed as vertical echo sounder, giving echo integration and TS information on the scattered fish and schools.

This tool would be in condition to overcome most of the problem existing at present : fish avoidance, fish observed close to the surface and the bottom, school structure and shape, real fish and school distribution, unbiased echo integration data, etc.

Finally we may add a few words concerning non conventional acoustic methods, such as non linear acoustics, which could help to resolve some of the acoustic problems detailed above, such as side lobes, etc. ; time reversed acoustics, which could take into consideration the problems related to multiple reflections on the bottom or the surface, or the heterogeneity or the medium (thermocline, background noise, etc.), although this series of methods is likely to be considered as potential improvement for a farther future.

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Appendix 3
ICES Study Group on Echo Trace Classification, La Coruna, 18-20 April 1998

Review of multi-frequency and wideband systems

by

D N MacLennan, A S Brierley and D Van Holliday

INTRODUCTION

At the meeting of the Study Group on Echo Trace Classification in Hamburg last April (ref. CM 1997/B:4), it was noted that wideband and other multi-frequency systems are in operation or under development, and that they provide additional information about the echo traces which could assist with echo trace classification. Furthermore, there may be other acoustic or non-acoustic techniques which could be used in this type of study.

In January 1998, we circulated a questionnaire in order to collect background information on this topic. A copy of the questionnaire is attached as Annex 2. The aim has been to cover both (a) development work, where the equipment is the end product, and (b) applications, where the equipment is used in a specific fishery and/or plankton research project.

We received a total of 13 completed questionnaires. This note is a brief summary of the findings which will hopefully provide a useful basis for further discussion in the Study Group. We have concentrated on presenting the factual information without attempting much by way of interpretation at this stage. We do not claim this is a complete coverage of relevant work in the field. It is hoped that, during the La Coruna meeting, any omissions can be identified with a view to updating this review for inclusion in the final SGETC report. A list of respondents is given at Annex 1.

The following numbered paragraphs refer to the information given in the corresponding section of the questionnaire (Annex 2).

1. Sources of information

The number of replies by country was as follows:

Australia	1	Iceland	1
Canada	2	UK	3
France	3	USA	3

All respondents were reporting personal research experience, except for two replies concerning "activities at my institute".

2. Equipment specification

2.1 Introduction

The responses generally fell into three categories: 1) the use of two frequencies; 2) use of more than two frequencies; and 3) the use of wide band acoustical systems. Only one respondent is working with a single frequency EK500. Each of these methods has advantages and disadvantages, with cost and availability driving the investigators to use existing gear, trying to extract as much information as possible from what they have. While this is clearly not optimal from a theoretical point of view, it is a practical approach and offers a good deal of promise in some environments.

2.2 The Two-Frequency Method

Theoretically, the two-frequency approach is particularly promising for locations in which the acoustical scattering is dominated by physically separate schools, layers or aggregations, each of which is characterized by a single species with a narrow size range. Several investigators report success with this approach while working with a variety of taxa. The basic theory is well established, but models are lacking for all but the simplest shapes. Several investigators are approaching the problem of classification with the two-frequency method from an empirical, rather than an theory based direction.

2.3 Multi-frequency Methods

Multi-frequency systems (> 2 frequencies) are summarized in the table below.

Summary of Multi-frequency Systems		
Lowest freq	Highest freq	Number
(kHz)	(kHz)	of frequencies
12	120	3
18	200	4
29	397	6
38	200	3 (2 cases)
104	700	5
265	3000	6
1100	3000	3

2.4 Wideband Methods

Investigations with three wideband systems were reported. Wideband systems have the advantage of allowing one to extract essentially continuous spectral shape and amplitude information from the echoes. One also has the choice of processing for high range discrimination (resolution) without necessarily obtaining spectral information. Some combinations of pulse waveform and processing can give both good range discrimination and doppler (target motion) information. The primary disadvantage is that bandwidth is generally a percentage of the center frequency of the transducer. As the percentage goes up, so does the cost, especially for high power transducers. Very broadband transducers (more than about 50% of the center frequency) are usually either limited in power, depth rating, or some other performance factor. Sampling the same volumes of water (i.e., the same animals) over the entire band of frequencies with a wideband system can also be challenging, as the beamwidth usually changes with frequency within the band. There are constant beamwidth, wide band approaches that can be used in transducer design, but none of these are known to be in use within the fisheries assessment community.

Summary of Wideband Systems			
Lowest freq	Highest freq	Waveform	Status
(kHz)	(kHz)		
20	80	modulate pulse	experimental & chirp (FM)
27	54	chirp	experimental
230	384	coded pulse	experimental

It should be noted that added bandwidth can carry more information about an object or animal that scatters sound, but that one has a number of choices in how one processes the echoes. The choice of the processing method ultimately determines the kind and amount of information that one can extract and use in a broader classification scheme. One must be careful to examine the signal-to-noise per unit bandwidth in such systems because opening the receiver bandwidth to more signal frequencies also opens the system to more noise. These considerations usually require the use of more complex waveforms and more complex signal processing.

3. What is the equipment used for?

Multi-frequency acoustic techniques have been employed in many of the world's oceans and seas over a variety of water depths, and to a lesser extent in fresh-water lakes. They have been used as an aid to species identification, to improve accuracy of biomass estimates, and for behavioural studies. Responses to this questionnaire suggest that a desire for information on the identification of acoustic targets is the motivation behind the greatest number of ongoing multi-frequency studies:

Use category	**No. of studies**
Biomass estimation	8
Fish behaviour	5
Target Identification	11
Other	4
Total	28

Equipment used for multi-frequency studies ranges from purpose-built instruments developed in response to knowledge of particular scattering properties of target organisms (e.g. TAPS), through specifically-modified commercially available instruments (including ADCP), to standard, off-the-shelf hardware (e.g. EK500). The equipment has been deployed from dedicated research vessels, from ships of opportunity, and on buoys: studies have also been conducted on encaged animals.

Multi-frequency techniques have been used for studies of fish, micronekton and zooplankton. They have been used to discriminate within and between these groups, and for discrimination of biological targets from physical phenomena such as bubbles.

Zooplankton/Micronekton: Multi-frequency techniques have been used to discriminate between and identify zooplankton/micronekton species/size classes, to estimate zooplankton abundance, and to draw inferences on zooplankton abundance and distribution relative to prevailing oceanographic conditions and environmental variability.

Fish: Multi-frequency techniques have been used to characterise aggregation patterns of several pelagic fish species, to identify fish species, and to discriminate between fish species. Resulting knowledge of the identity of acoustic targets, and target behaviour, has in some instances been used to improve accuracy/precision of biomass estimates.

4. Data analysis

4.1 Use of standard packages or special software

A variety of packages have been listed ranging from ordinary spreadsheets like MS Excel to Matlab (4 cases), SPSS and Oracle (1 case each). Three respondents said they had developed their own software. Of course, in the case of Matlab, in-house software in the form of Matlab procedures would still be required. It is likely that such routines would be designed for the specific application and may not be useful to other users unless the application was the same. The replies did not generally say whether the in-house software was just that, as opposed to being fully developed and commercially available (presumably that would be the case for companies selling hardware).

The Simrad BI500 system is the one example noted of a commercially-available package which is "standard" in the sense of being useful in a range of applications. The BI500 was being used by four of the respondents. However, a report from Canada described an integrated software package (CH1) which is being developed. This uses a standard data format (HAC) and combines several data analysis approaches.

4.2 General approach and methods

This question really covered three different aspects: (a) Selection of records for archiving; (b) analysis methods and (c) display of data and/or results.

(a) Most respondents gave comprehensive details of the collected data. These might include SV by depth bin at various frequencies, either as the raw values or as summary statistics, and supporting information such as environmental observations. In this type of work there is the potential for collecting very large quantities of data and some degree of selection or summarising is normally essential.

(b) There are several examples of discriminant analysis and neural networks being used for school identification. These appear to be the most promising approaches at present. Time/frequency analysis was mentioned but it does not seem to have produced useful results so far. In the case of plankton studies, models are often used to interpret the acoustic data in terms of size distributions. The "truncated fluid sphere" and the Holliday-Greenlaw algorithm are particular examples of the modelling approach.

(c) In some cases the display of data is part of the analysis procedure when, for example, the user has to control the selection of schools for processing. Apart from echograms, there is also the problem of how to present statistical results in an informative way. Some form of picture presentation is an obvious way to show a mass of data so that the important features are apparent. GIS (Geographic Information Systems) have been mentioned as a useful approach in this connection.

5. Reports and publications

The references quoted in the questionnaires have been extracted into one list which is given in the bibliography at the end of this note.

6. Potential for further development

The respondents uniformly reported that new methods for echo trace classification were needed in support of fisheries assessment efforts and that the exploitation of the frequency domain by using multiple discrete frequencies and /or increased bandwidth centered about a single frequency were attractive candidate approaches to the classification / identification problem. These responses are consistent with the communications theory / signal processing theorem which relates signal bandwidth and the amount of information that can be transferred over a communications channel. While the details differ, both wide bandwidth systems centered at a single frequency and multiple, discrete frequency systems may exploit the consequences of increased bandwidth.

Multi-frequency and wideband methods are relatively well developed for plankton and have become relatively routine within some of the biological oceanography community. The principal product of these developments have been measurement of biomass by size in relation to the physical, food and chemical environment. Unless size is a unique discriminant within a particular environment, these methods are not yet used alone for species identification. Additional approaches such as multi-frequency, multi-static methods are under investigation and seem to have some potential for extraction of shape and several physical characteristics such as compressibility and density contrast of the animals with sea water.

In the opinion of the respondents, the exploitation of multiple frequency and wide band acoustical signals for classification and identification of fish is a promising avenue for future investigation. Multi-frequency methods are currently being applied to nekton in a variety of locations and for a variety of taxa. However, the application of the technology for fisheries assessment is in its infancy, with a need for application to additional species at different depths, in different seasons, and in a diversity of geographical locations. The need to examine aggregations of mixed populations or assemblages, especially *in situ*, was explicitly noted.

Several responses directed attention to the need to include all available information in classification processing, not just acoustical data. This means including such parameters as location; season; time of day; depth of the target; characteristics associated with its aggregation (e.g., layering, schooled, size, shape); the environmental or ecosystem characterization (e.g., association with food and the physical environment); historical catch data; bottom characteristics (e.g., topography, vegetation, bottom type), etc. It is thought that the inclusion of as many factors as is possible might enhance the power of future discriminant or other analyses leading to species identification. The need for mathematical models that are useful for a wider variety of species, optimization of the frequency bands to be utilized for particular species and the spacing or resolution (number of frequencies) within those bands were also mentioned.

One respondent summed it up rather well with the comment that "Multi-frequency is definitely the way to go ... imagine looking at the world through sunglasses that allowed us to see in only ONE colour ...".

7. Any other comments or views on echo classification problems.

Use of multi-frequency acoustic techniques, and associated statistical analyses, have proved to be quite successful at target identification, achieving between 70 and 90% correct species classification in some instances. Correct species identification has though been more successful in the controlled conditions of cages than in open ocean, and problems have been encountered when trying to classify mixed species aggregations.

Technical problems associated with multi-frequency studies include:

- low operating ranges of high frequencies;
- differences in beam angles / sampling volumes at different frequencies;
- different noise levels / appropriate thresholds at different frequencies.

Although there have been some notable successes, the general application of multi-frequency techniques to fisheries and plankton acoustics is in the early stages of development, and much remains to be done before autonomous acoustic classification of species can become routine. However, it seems likely that many of the associated problems can and will be overcome, and multi-frequency data are likely to be used increasingly as target identifiers, augmenting potentially biased information on species composition obtained from nets.

The more lines of information (discriminating characters) one has available, the greater the likelihood of correct target identification: future developments leading to improved target identification may include integration of acoustic data with optical sampling (OPC) and Doppler information. Further development / refinement of scattering models for more species will improve the efficacy of inverse methods.

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Annex 1

List of respondents who completed questionnaires in the 1998 survey

NAME	INSTITUTE
Aukland	Marine Laboratory, Aberdeen, Scotland
Brierley	British Antarctic Survey, Cambridge, England
Diner	IFREMER, Plouzane, France
Gordon	RD Instruments, San Diego, USA
Holliday	Tracor Applied Sciences, San Diego, USA
Kloser	CSIRO Marine Research, Hobart, Australia
Lebourges-Dhaussy (2 different applications)	ORSTOM, Plouzane, France
McQuinn	Institut Maurice Lamontagne, Quebec, Canada
Reynisson	Marine Research Institute, Reykjavik, Iceland
Simmonds	Marine Laboratory, Aberdeen, Scotland
Trevorrow	Institute of Ocean Sciences, Sidney BC, Canada
Wilson	Alaska Fisheries Science Center, Seattle USA

Appendix 4
Internacional Council for the
Exploration of the Sea.

FAST Working Group
Echo Trace Classification
Study Group
Working Paper

Report on developed software for visualisation of acoustic information.

By

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INTRODUCTION

AT the meeting of the SGETC in Hamburg, it was agreed that information on software developed by the different teams working on acoustics and Echo trace classification will be collected. In December 1998 a questionnaire was distributed in order to collect this information on software tools. This questionnaire was focused in different aspects that we have considered important for the definition of an acoustic software tools.

Because some tools in the past were dedicated to acquisition, the questionnaire was divided in two sections : acquisition and processing.

A total of 19 questionnaires were received in April 15[th], 1998 and all of them were resume in a table. Some of the answers to the questionnaire were in the form of software description and were also introduced in this paper as a table. No direct contact with the software was done by the author. Only the description of the software tool by the contact person from each team is used in this paper and then all opinions are of particular subjectivity but the aim of the questionnaire was to collect information not to use it as recomendation.

A total of 19 questionnaires and descriptions were received which corresponds to 15 institutes or laboratories (table 1). Some of these institutes or laboratories sent several questionnaires. Also is included a questionnaire that describes BI500 (Bergen Integrator) software as the tool used. We have considered useful to include this tool in the collate because it is representative for some acoustic research teams. Biosonics Echobase software is also one of the tools included.

These 19 questionnaires include old software versions (2), new developing software (4) not described here, and standard packages as BI500 and Echobase (2).

For acquisition of echosounder signals, 11 use Simrad BI500 or EP500 and 1 use BioSonics. Only 6 use his one software for acquisition and from this 6, 2 corresponds to a commercial equipment (Movies).

In figure 1 some resume information is showed. From the total of the questionnaires, it is noted that close to 100% of the answers use 38 kHz echosounder, 70 % use 120 kHz, 50% use 200 kHz and close to 30% could use any echosounder. In this case, the echosounders are Simrad and the acquisition tools are BI500 files.

EK500 is the echosounder more used (70 %) but other equipments are here represented as OSSIAN and Biosonics. The range of frequencies is from 12 kHz to 200 kHz.

It is evident that these tools are developed for Biomass estimation or other studies like experiments on Target strength or fish close to the bottom. But in some groups, the evolution of this software is to include further analysis of echo signals to obtain more accurate biomass estimation in special conditions like bottom communities or school and species classification.

From the total questionnaires answers we have classified as "true" echotrace classification or school classification or species identification software 7 over 19. These 7 include 2 of the same group that corresponds to new and old version of the sofware.

Other software include acoustic data coupled with environmental data as CTD or ADCP data. In this case we have define it as Integrated Acoustic and Oceanographic tools. Those include 5 over 19.

And finally, due that some groups are working with Image Analysis and graphic tools, we have defined a group of Graphic Software, which include those tools that permit some editing and graphic analysis (9 /19).

The Echotrace, school and species classification tools are all of them based on Ping but the processing could be based on pixel or signal (Sv) information (2:5). All with exception of Movies are integrated in a copmercial DataBase (Oracle, Paradox, Acces, PostGres) and one is introduced in a GIS (Geographic Information System).

Systems are based on Work Stations and PC, and programming tools are C, C++ (6) and turbo Pascal (1), which means low level languages.

The methodologies used varies from multifrequency comparison for krill species classification or identification, ping analysis for school description , environmental and morfological descriptors and biomass estimation per school.

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Appendix 5 Not available

Appendix 6

On Visual Scrutiny of echograms for acoustic stock estimation

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Introduction

Acoustic surveys are widely and successfully used for the assessment of pelagic resources (MacLennan & Simmonds 1991). One major part of the analysis of the results of such surveys is the visual examination of the echogram and the partitioning of the calculated echo-integral into categories, usually for the target species and for other scatterers. This step is usually entitled "scrutiny" or "scrutinization" Unlike most of the other steps in the analysis, scrutiny is essentially subjective, and requires an experienced operator. The operator is required to examine the echogram, and decide whether any of the echotraces observed belong to the target species, or contain the target species mixed with other species. These traces could be schools, layers or scattered fish. The decision is largely based on data from fishing activity during the survey. Ideally, fishing operations will have been carried out on all major fish aggregations seen during the survey. However, the previous experience of the operator in this area e.g. in previous years or in similar situations, will also have a bearing.

Until objective techniques are developed to determine the species make up of every echotrace this scrutinization process remains a central part of the analysis. This then raises the question of how robust or consistent such analyses are. In the best situation, a survey will be carried out and analysed by the same scientist over a number of years and the results of that survey will be used on their own as an input to the assessment process, either as an index or as an estimate of absolute abundance. In this situation, while the individual scientist may introduce a bias in the biomass estimate, it is to be hoped that he will be consistent over a number of surveys. A more difficult situation arises when the results from a number of different surveys are combined to give an overall biomass estimate or where there are changes in the personnel involved in the conduct and analysis of those surveys. Both the latter conditions occur in the ICES coordinated herring acoustic surveys in the North Sea. The survey is carried out by vessels and personnel from Scotland, Norway, Denmark, Germany, Sweden and the Netherlands. Each survey is analysed in isolation and the resultant numbers and biomass distributions are combined to produce an estimate of the overall herring abundance in the North Sea. A number of questions may be asked. Is the approach to the scrutiny the same for all the teams involved? Are there likely to be problems when the personnel involved are changed?

To investigate this, we assembled teams from all the nations which take part in the coordinated surveys for a scrutiny workshop. Each team was required to provide the data from a typical days herring acoustic survey in the North Sea, along with the trawl information pertaining to that day and other ancillary information. The teams were then asked to carry out a scrutiny exercise on all the data sets provided to the best of their ability. For comparison purposes the originators of each data set were also required to analyse their own data set. The outcome of these analysis were then collated and the areas of disagreement examined.

The present paper presents the results of the scrutiny workshop, a discussion of the results and an appreciation of the robustness of echogram scrutiny.

Materials and methods

Five data sets were made available for the workshop. Each data set covered a single typical day from one of the component surveys of the ICES coordinated North Sea herring acoustic survey. The five data sets were from:

- The Scottish survey in the NW North Sea near Shetland FRV *Scotia*
- The Scottish survey on the west coast of Scotland west of the Hebrides MFV *Christina S*
- The Norwegian survey in the NE North Sea near the Skagerak FRV *GO Sars*
- The Netherlands survey in the western Central North Sea near the Scotland/England border FRV *Tridens*
- The German survey in the eastern North Sea in the area of the Heligoland Bight. FRV *Walther Herwig*

All the surveys were carried out using SIMRAD EK500 38 KHz echosounders according to the procedures laid down in the manual for herring acoustic surveys in ICES divisions III, IV and VI, presented as an appendix to the report of the ICES Planning Group for Herring Surveys (1994). With the exception of survey 2 the echogram data were recorded using the SIMRAD BI500 software as INGRES database files (Knudsen 1988). The data for the *Christina S* survey were presented as a colour paper printout with the integrator output presented as a cumulative line and in totals by layer for each sampling period. The database files were loaded onto SUN workstations and the analysis carried out using the scrutinise programme on the BI500. The results of the analysis were then downloaded as MS Excel files for analysis on PC. For the *Christina S* survey the data were entered directly by hand into the Excel spreadsheet.

The analyses were carried out by six teams of two scientists each, with each team analysing data sets from all five surveys, including the data set for which they were the originators. The teams were selected where possible to be from the same country and used to working together. Each team were provided with the survey data sets on the BI500 system (except the *Christina S* survey), paper printouts of the same data, information on trawl hauls carried out on the appropriate days and for the days before and after, and a brief description of the circumstances under which the data were collected e.g. weather conditions etc.

The analysis thus produced six independent scrutinies of each of five survey data sets. The mean allocated echo integral (the "result") with standard deviation (SD) and coefficient of variation (CV) were calculated for each survey. The results of the six scrutinies were plotted as mean (with 95% CI) for each ESDU (Elementary Sampling Distance Unit) in the survey data sets. Each team's results were also expressed as percent deviations from the originator's results and the mean result.

It was considered important to be able to express the results in a way which demonstrated how much variability might be associated with the scrutiny exercise for the whole combined survey. To this end the variance was calculated for the results of each survey data set. The pooled coefficient of variation for all the surveys was calculated using the following relationship:

$$CV_{all} = \frac{\sqrt{\sum_j (S_j . N_j)}}{\sum_j (EI_j . N_j)}$$

Where:

CV_{all} = Coefficient of variation for all surveys combined

S_j = variance of the jth survey

N_j = Number of days of the jth survey

EI_j = Mean echo integral for the jth single day of the survey

The calculation is based on the assumption that the variance calculated for one day of a survey is representative of all days on that survey. The survey variance can then be considered as the multiple of the daily variance and the number of days, and that the variance from each survey can be treated as additive for the whole combined survey. The CV is then calculated using the allocated daily echo integrals multiplied by the number of days for each survey and summed for the combined survey.

Results

Figures 1 - 5 show the mean results by ESDU for the five different surveys plotted with 95% CI. Figure 6 shows the percentage deviation of each team from the mean for each survey and Figure 7 the deviation from the originators results for each survey. Table 1 gives the means, CV values and number of days for each survey.

Table 1.

Survey	Mean Echo Integral	Number of days	CV
Christina S	5975	15	0.10
GO Sars	6142	17	0.23
Walther Herwig	13808	15	0.05
Tridens	14811	15	1.14
Scotia	8938	15	0.09

In general the results show reasonable consistency between the teams carrying out the scrutiny. The results for *Christina S, Walther Herwig* and *Scotia* all show a close correspondence for all the teams, with CV values for a single day of 10% or less. The results for GO Sars and Tridens show much higher CV values, and these are worth examining in more detail.

For the *GO Sars* survey the high CV is largely driven by a disagreement in the assignment of the echo integrals in two ESDU. The largest discrepancy is in ESDU 21, with a smaller deviation in ESDU 16. This survey is mainly characterised by small dense schools of herring in the upper 20m of the water column. In ESDU 21 the echogram also included a large pillar like mark on the seabed at about 45m. In the original echogram (Fig. 6a) the mark was dense enough for the system to regard it as seabed and so it was not initially integrated. This type of mark is characteristic of herring marks in the *western* North Sea, and three teams assigned it as such, while the remaining three did not. As this was a large school it contributed substantially to the variance. In ESDU 16 another mark was seen at about 70m in mid water (Fig. 6b), although here only two teams assigned the school as herring.

There is a different explanation for the wide range of the results of the analysis of the *Tridens* survey. This survey was characterised by a number of large schools in mid water in the middle of the day (ESDU 21-29).

The problem here was in deciding what the species composition of the schools was. There was no trawl taken at this time, and the teams had to rely on a number of trawls carried out nearby, both before and after. The trawls were mostly made up of mixed Norway pout and herring. Based on these the originators of the data believed that the schools were approximately 15% herring and 85% pout. Three other teams used approximately the same ratio. One team chose to assign the schools as 100% herring and another as 0%.

The CV for the pooled results gives a value of 8.7%. This can be taken to indicate that the variability introduced into the combined N. Sea survey by inconsistency in the scrutiny process.

Discussion

The findings of the present study indicate that the results of the combined acoustic survey for herring in the North Sea are reasonably robust to variability in the scrutiny process. The five days survey data were chosen as reasonably typical of the survey data sets as a whole, and, additionally, to contain significant quantities of herring. Three of the data sets yielded CV values for the analysis of 10% or less, one survey had a CV of 23% and the last had a CV of 114%. Based on experience this pattern fits generally with what would be expected within any one survey - 3 out of 5 days would be relatively straightforward to assign, one would give some difficulty and one would be expected to be quite difficult. It is interesting to note that the *Christina S* survey which had to be analysed from the paper echogram did not result in significantly higher variability than the *Scotia* or *Walther Herwig* data sets.

The circumstances of the workshop were designed to give as realistic as possible a picture of how the scrutiny process works. However a number of factors could be considered as making the process more difficult for the teams than it would normally be.

- The teams were given only one days survey data. Under normal conditions they would have up to 17 days.
- The teams would normally have carried out the survey themselves. Thus, they would have been able to supervise the data collection and would have controlled the location and conduct of the trawling.
- The teams would normally have included at least one person who was experienced in acoustic surveys in that area in previous years.
- The analysis would normally take place either during or immediately following the survey, not a year later as in this case.
- All the teams had some experience using the BI500 software to analyse acoustic surveys. However, some of the teams use this method routinely, while other use a combination of visual examination of the paper echogram with in house analysis software, and minimal or no use of the BI500. Survey 2 required analysis of the paper echogram **only**. Again some of the teams were unused to this approach.

It would be reasonable to assume that any of the teams would be likely to achieve better results if some or all of the above difficulties were reduced. The fact that a pooled CV of 8.7% was achievable under these circumstances is encouraging.

The situations where there were substantial differences between the teams also provide useful information on the problems associated with this process. In the case of the *GO Sars* survey the problems lay in some of the teams assigning the mid water marks as herring. As mentioned above, the area is characterised by small, near surface schools. All the trawls in the area provided for the analysis had been taken on these surface marks. There was no trawl data to indicate what species made up the mid water marks. This was a result of the originators experience that ALL the herring were contained in the near surface marks. Notwithstanding this, three of the teams still chose to assign these marks as herring. The rationale for this decision appears to lie in the experience of those teams. Two of the teams were used to surveying in the western North Sea where such marks would almost invariably be herring. Given that the schools had not been sampled, their experience led them to conclude that they were herring schools. Equally, the originators experience led them to conclude that all the herring were in the surface waters, and so these schools were NOT herring. Given the teams differing experience both decisions were, therefore, quite rational.

In the case of the *Tridens* survey, the situation is remarkably similar. The particular schools which caused problems were not sampled by trawl. The teams than had to decide how to assign these schools based on the nearest trawl samples. This area of the North Sea is characterized by a mixed pelagic population of herring and pout, usually within 10-20m of the seabed. It is not known if these species school together, however, trawling operations will often bring up mixed catches of both species. It is well known that commercial fishermen find the schools in this area difficult to distinguish and this problem has been mentioned regularly in the combined acoustic survey report. Given that this group of schools was not sampled, the operators had to decide which of the nearby trawls was most diagnostically useful. This decision can depend on a variety of factors such as the appearance of the schools, the water depth, the time of day etc. In this particular case four of the teams used the average composition of some of the neighboring trawls, although the trawls used varied between teams. One team decided that as no trawl sample was taken, they could not assign any of the fish as herring. The remaining team decided that they looked like herring schools as seen on the other trawls, and that pout were unlikely to school with herring, and hence assigned the fish as all herring.

In both the examples cited above the problems were caused by the need to assign schools in the absence of appropriate trawl data. Where the teams were provided with trawl data which adequately supported the survey data the pattern of scrutiny was remarkably similar. This highlights the importance of maintaining a high level of fishing effort during acoustic surveys. The main uncertainties arise when species assignments have to be made with poor trawling data.

In conclusion, the workshop has illustrated that, provided the operators have access to good quality trawl data, the results of the visual scrutiny of echograms are relatively robust to the behaviour of different operators. The ability of the teams to produce generally consistent results suggests that the combination of post analysis survey results (biomass and numbers) is valid. The findings also suggest that changes in personnel may not be critical for the consistent analysis of these surveys, provided that the new personnel are trained by their predecessors or by other participants in the coordinated surveys.

References

MacLennan, D.N. & Simmonds, E.J. 1991. Fisheries Acoustics. Chapman & Hall, London & New York. 325pp.

Figure 1. Scrutiny Results
Christina S

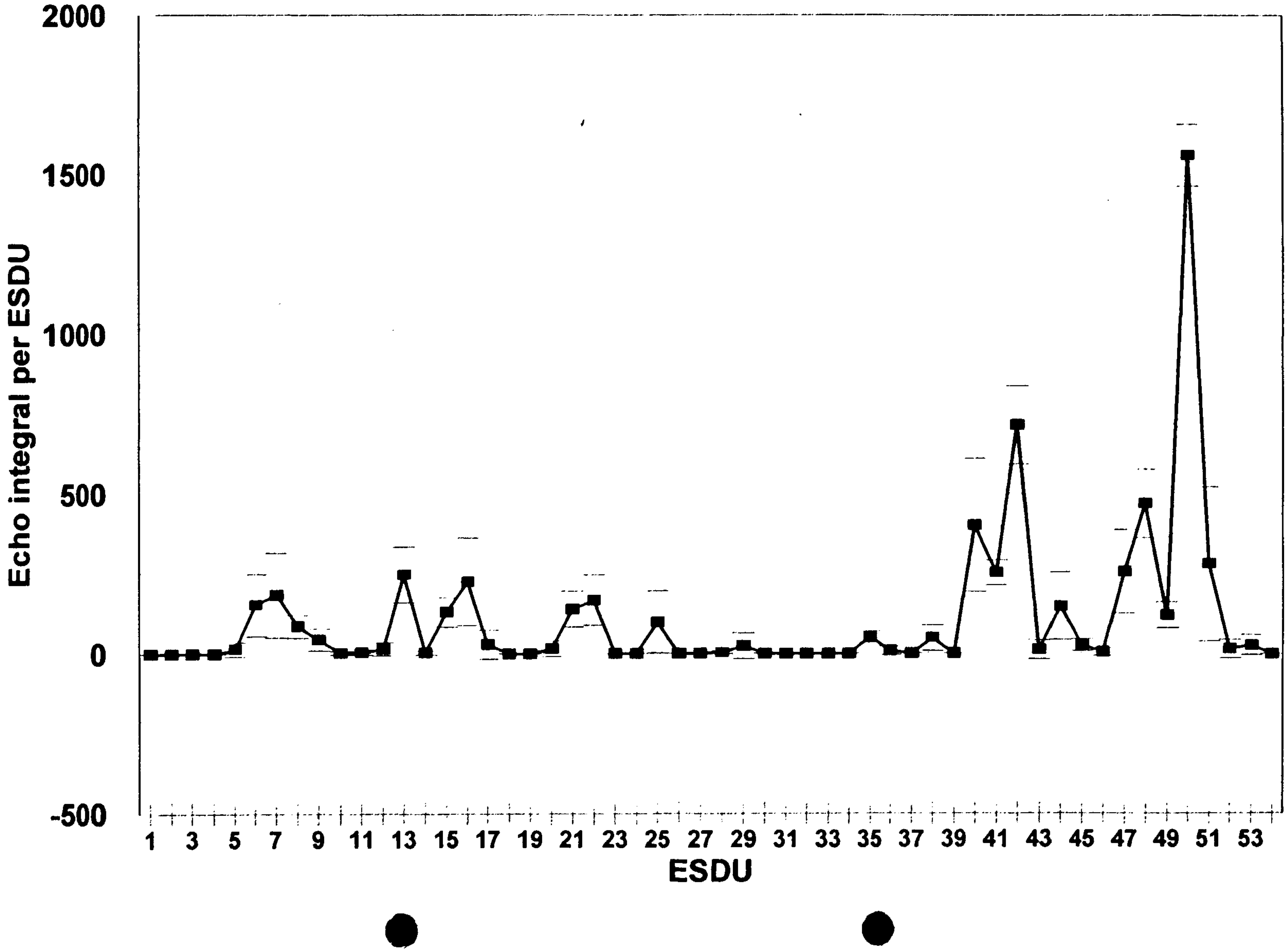

Figure 2. Scrutiny Results
GO Sars

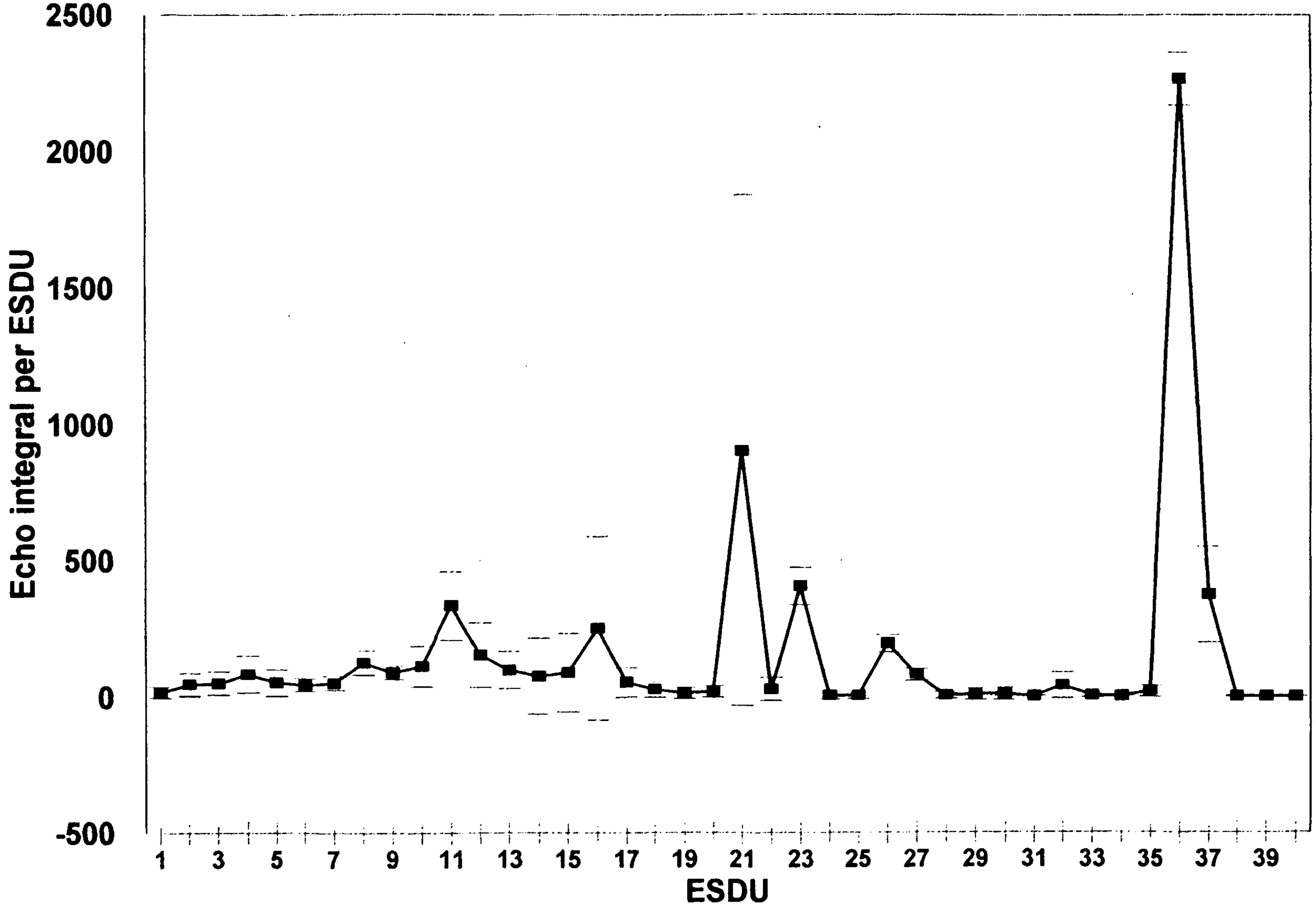

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Figure 3. Scrutiny Results
Walther Herwig

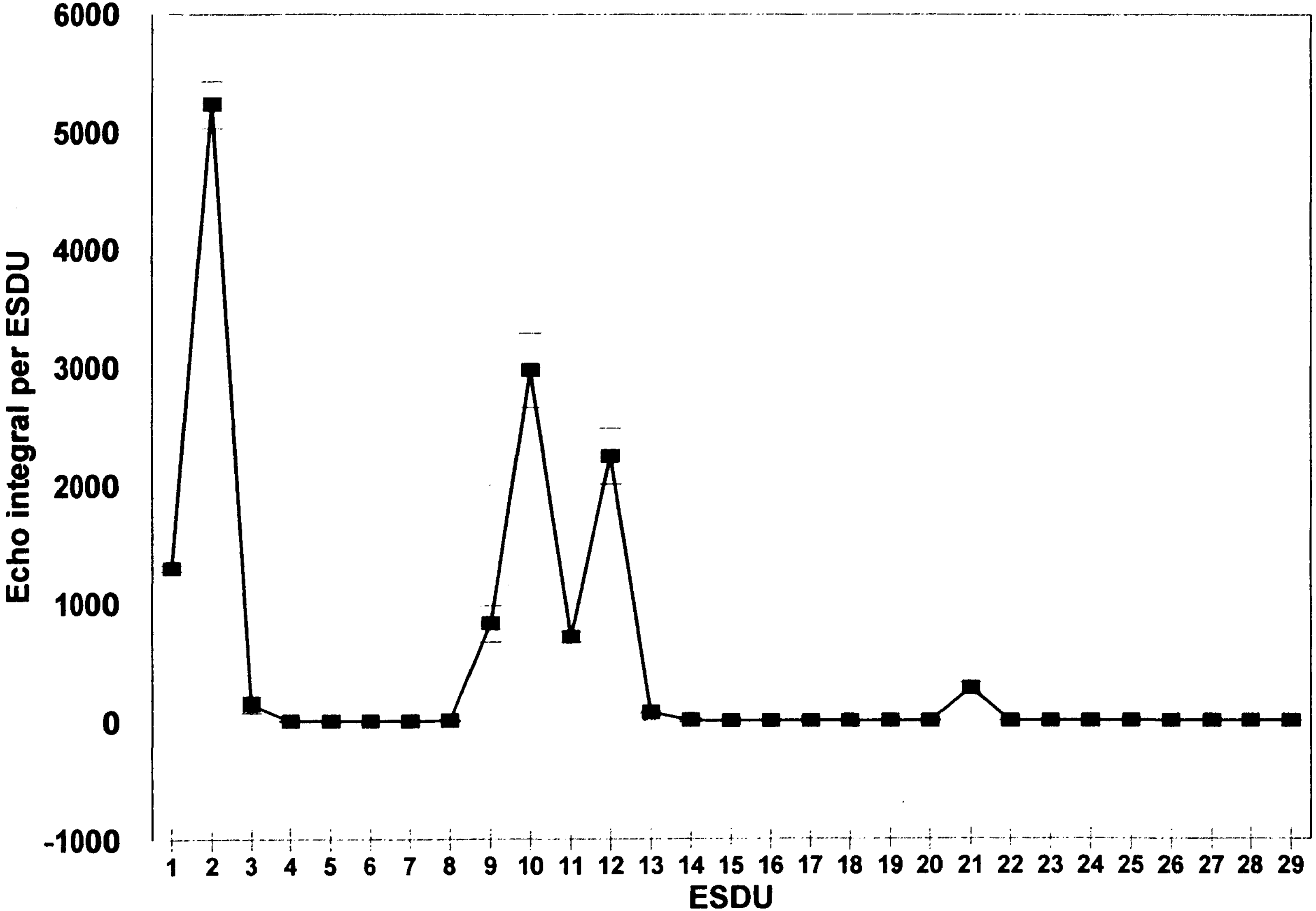


Figure 4. Scrutiny Results
Tridens

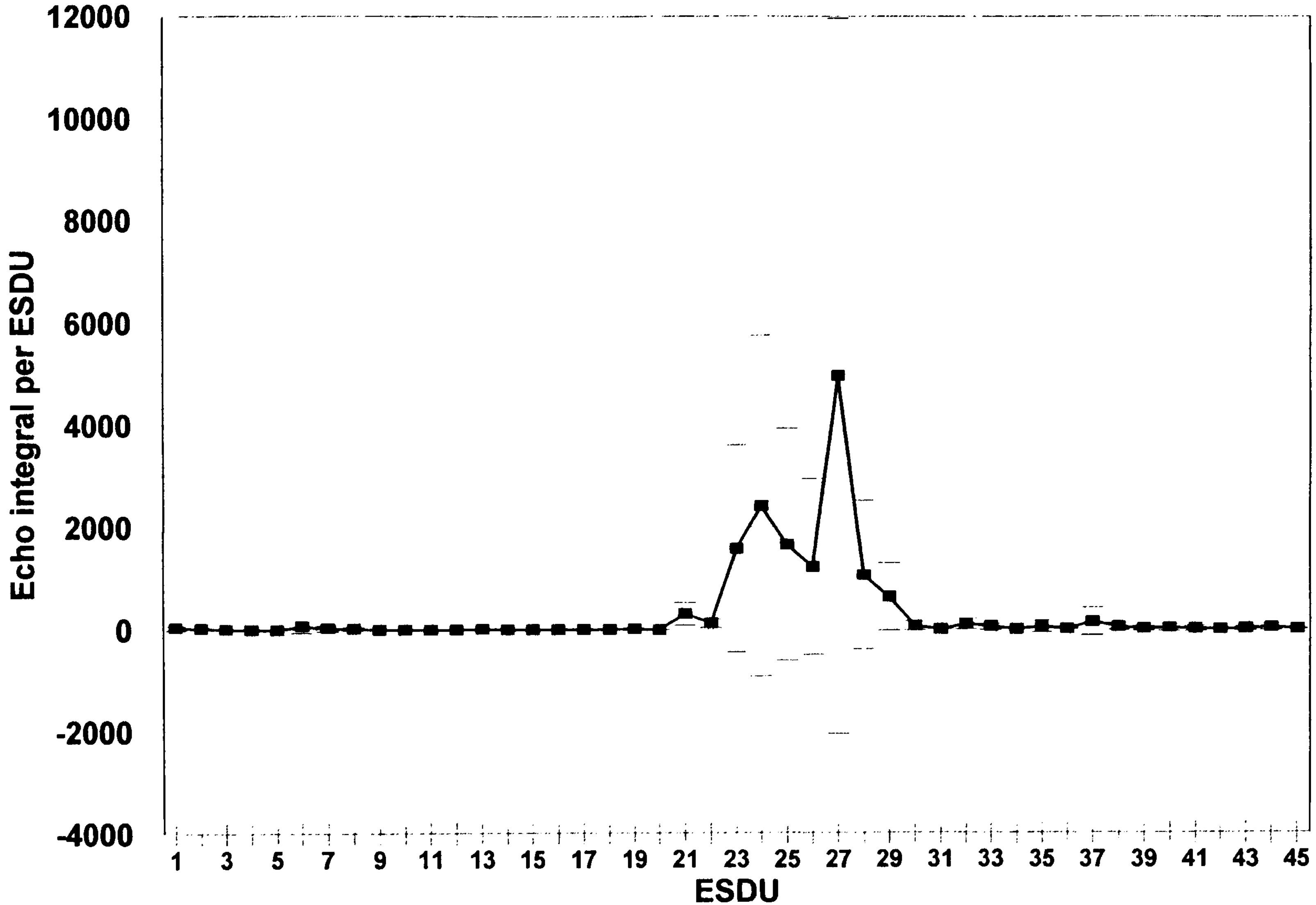
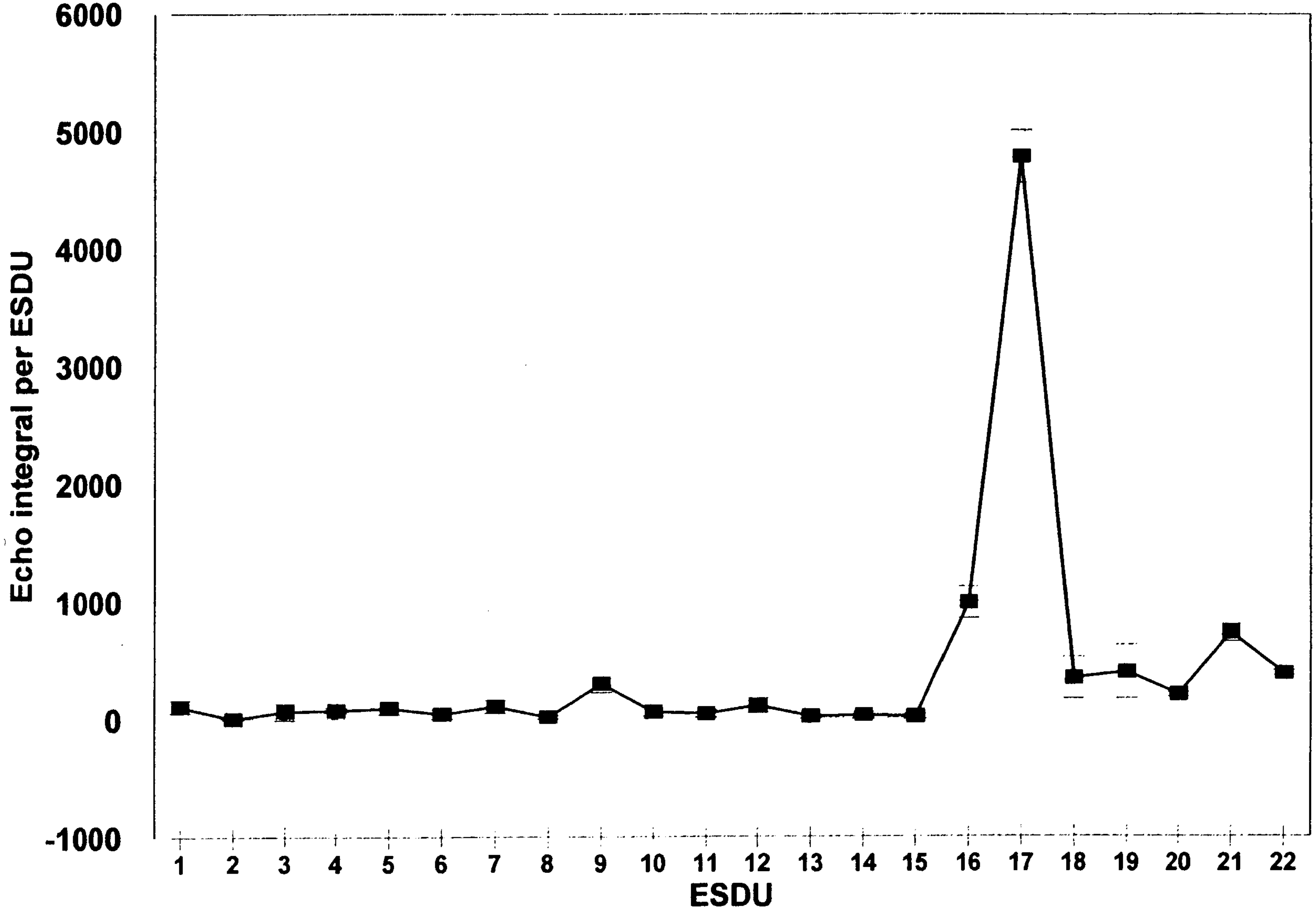


Figure 5. Scrutiny Results
Scotia



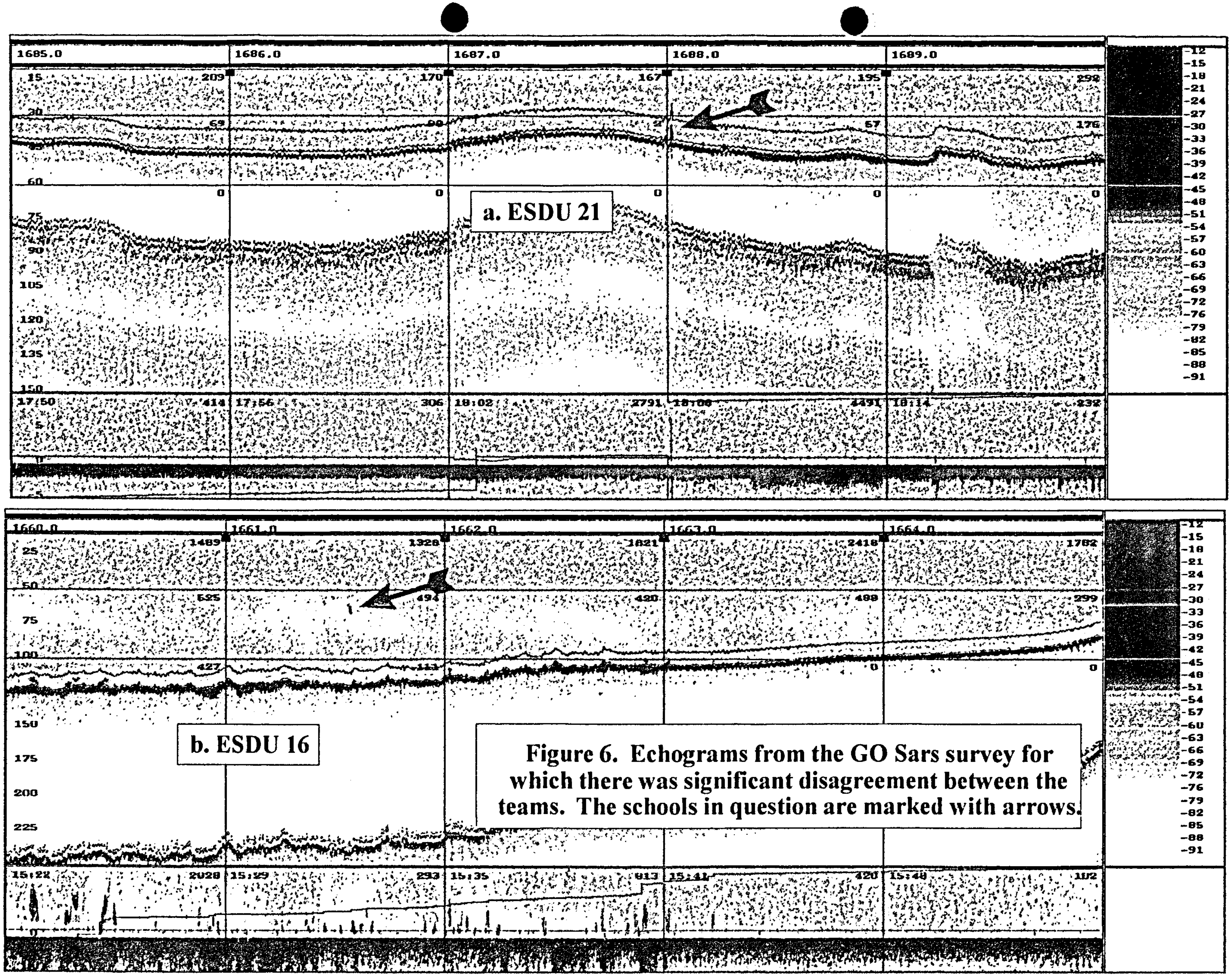


Figure 6. Echograms from the GO Sars survey for which there was significant disagreement between the teams. The schools in question are marked with arrows.

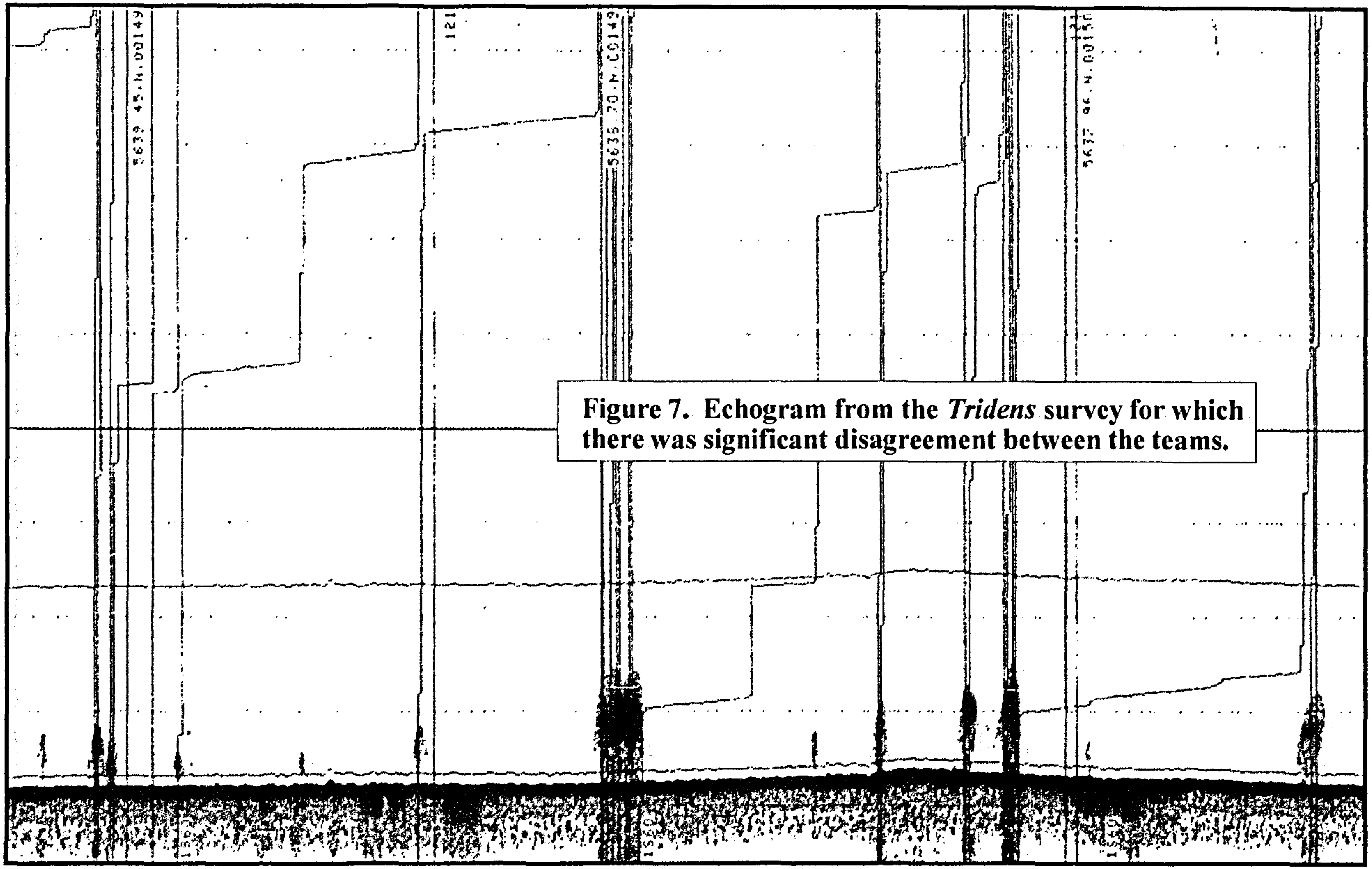


Figure 7. Echogram from the *Tridens* survey for which there was significant disagreement between the teams.