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# The application of multibeam sonar technology for quantitative estimates of fish density in shallow water acoustic surveys

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**Abstract** − The paper describes the main drawbacks in the application of conventional acoustics in shallow waters, and reviews the advantages and limitations that existing multibeam sonar present in these ecosystems. New techniques and methods for adapting multibeam sonar to shallow waters are proposed and discussed. A method for analysing acoustic data from shallow waters through image analysis process is presented and some examples are considered. The results show that scattered fish can be observed individually and counted, and that schools are described in their morphology and behaviour. From these results an 'ideal' acoustic device is defined: a sonar operating at more than 400 kHz with a coverage of at least 120° in one direction and, depending on the needs of the user, 15° or 1° (which can be modified easily) in the perpendicular plane. The beam opening–angle is 0.5° in the centre beam, increasing to 1.0° at the 60° steer–angle, giving a total of 240 beams. Multibeam sonar data could be used for several purposes in shallow waters, in particular to estimate fish density and biomass, and study spatial and temporal behaviour of fish.


**multibeam sonar / horizontal acoustics / shallow waters / 3D image analysis / spatial statistics**

**Résumé − Applications du sonar multi-faisceaux aux prospections acoustiques en faibles profondeurs et à l'estimation des densités de poissons.** Ce travail décrit les principaux points faibles de l'application des méthodes acoustiques dans les milieux aquatiques de faible profondeur, et met en évidence les avantages et limites que présentent les sonars multi-faisceaux (MBS) dans ces milieux. Il présente une méthode de collecte, d'analyse et de traitement des données obtenues en «petits fonds» au moyen d'un sonar multi-faisceaux, avec quelques exemples. Les résultats montrent que les poissons dispersés peuvent être observés, individualisés et comptés; par ailleurs le MBS fournit des informations sur la morphologie et le comportement des bancs. Ces résultats permettent de décrire le système «idéal»: sonar multi-faisceaux de fréquence 400 kHz, angle d'observation de 120°, pour un angle dans le plan perpendiculaire de 1° ou de 15° (modifiable par l'opérateur). L'angle des faisceaux individuels peut varier de 0.5° dans le centre du plan d'observation à 1.5° dans la périphérie, pour un nombre total de 240 faisceaux. Le sonar multi-faisceaux peut être utilisé en faibles profondeurs (inférieures à 5 m) dans divers buts, tels que l'évaluation de la densité et de la biomasse en poissons ou l'observation des structures spatiales des concentrations et du comportement des individus ou des bancs.


**sonar multi-faisceaux / acoustique horizontale / faibles profondeurs (« petits fonds ») / analyse d'image tridimensionnelle / statistiques spatiales**

## 1. INTRODUCTION

During the last two decades, single-beam echo integrators have become the standard tool for acoustic estimation of fish abundance (Simmonds et al., 1992). One critical aspect of the acoustic sampling is the assumption of the stochastic occurrence of fish within and around the sampled volume, which can be violated due to the natural behaviour of the fish in avoiding the research vessel (Diner and Massé, 1987; Misund, 1997). Measurements on number, size, shape, density and depth of the schools can be biased in a variable manner according to the species, season, as well as geographic and environmental parameters (MacLennan and Simmonds, 1992). In very shallow waters (bottom depth < 5 m) the application of single beam methods results in a very difficult compromise between sampling volume and resolution of fish targets from the sea surface and bottom echoes. Multibeam sonars (MBS), however, achieve an increased acoustic

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sampling volume by minimising the transmit pulse (1–3°) and maximising the effective beam angle to 90–180° by combining several narrow beams (48–120) which operate together and image the entire swath width each time the sonar pings.

Advanced MBS have been used over the last few years to estimate the abundance of fish near the sea surface, investigate swimming and avoidance behaviours, as well as study fish migration (Gerlotto et al., 1994; Gerlotto et al., 1998; Gerlotto et al., 1999). Most of this work was carried out using analogue output by digitising the video images ping by ping (Mayer et al., 1998). Although a more direct analysis of raw digital data may be a standard practice in the near future, a tool capable of analysing video-images acquired from the video sonar output may be useful for research in shallow waters, considering that the degradation of the information remains acceptable, while the cost is dramatically reduced and allows the use of any MBS. Some methods and results on image analysis are presented in this paper. Finally the characteristics of an 'ideal' tool for shallow water acoustics are defined.

## 2. MATERIAL AND METHODS

### 2.1. Limitations in the use of single-beam sonar in shallow waters

There are several problems that are particular to shallow water applications, among which the five most important are certainly the following.

– The distance to the target. The theory of underwater acoustics requires that the target dimension *l* be negligible compared to its distance *R* to the transducer. MacLennan and Simmonds (1992) observe "If *R* is large enough to be outside of the near field of the target, which means that *R* has to be much greater than the linear size of the target, but not so large that absorption losses are important, then the cross section $\sigma$ [applies]". This condition applies in most of the cases in deep areas but less often in shallow waters: in some extreme cases, *l* can present the same order of magnitude as *R*. The near field of the transducer also must be taken into consideration. In the case of shallow waters, where very narrow beams are required, this near field may dramatically increase. MacLennan and Simmonds (op.cit.), for instance, give the following equation for measuring the distance of the near field as (equation 1):

$$R_0 = \frac{2d^2 f_0}{c}$$

where $R_o$ is the near field distance, *d* the diameter of the transducer, $f_o$ the frequency, and *c* the sound speed in the water. These authors present the case of a circular transducer, frequency 120 kHz with beam pattern 2.5°: for a 30 cm transducer diameter, the near field is 14.5 m. Even though other methods and definitions are used (e.g. the ratio of transducer surface area to the acoustic wavelength), the near field remains important (5.7 m in this case). This explains why the usual echo sounder transducers used at this frequency in shallow waters have a wider beam and a smaller surface, giving a near field shorter than 1.5 m.

– The multiple reverberations. When using sound transmission horizontally, the sound reverberates on both the bottom and the surface, and is forced inside a thin plate, which changes completely the sound scattering characteristics. This is valid for the sound transmission as well as for the echo reflection. Trevorrow (1997) presented some clear manifestations of this phenomenon in shallow water acoustics. It has at least two major implications: first the usual equations of sound dispersion do not necessarily apply. Then, the echo characteristics will represent a complex synthesis of interactions between the target and the boundaries of the area. Applied to our fish echoes, and depending on the lengths of the different paths, the echo will appear either longer or even multiple.

– The sampling volume. It becomes extremely small in shallow waters, whatever the method employed. Vertically the volume is definitely insufficient and not representative of the area. Horizontally another phenomenon may occur: side lobes may introduce false echoes due to the bottom, making it practically impossible to discriminate biological target and noise, particularly if the survey is done with a ship moving along a transect.

– The significance of target strength (TS) values. Shallow waters, and more generally short distances, imply that high frequencies be selected, in order to allow a reduction in the pulse length, and necessitate the use of narrow beam transducers with reasonable dimensions. This may induce an increasing directivity of the fish echoes, and a high variability of TS according to the tilt (or incident) angle of the fish main axis. Kubecka (1996), for instance, showed that with 120 kHz used horizontally, the fish mean TS could present variations greater than 30 dB, depending on the fish position. Moreover, it is worth noting that most of the experimental work on TS has been done at lower frequencies (usually 38 kHz) and longer range, and this point is practically undocumented in these extreme conditions: the significance of TS value may be quite different in shallow waters (Barange et al., 1996).

– The fish behaviour. At small distances, in particular vertically, fish behaviour becomes a major source of bias. We showed that extreme differences may occur in a single region, depending on how fish behaviour is taken into consideration: by day, in an area of clear water with depth between 3 and 5 m, no targets were recorded, while by night, in complete darkness and using adapted methodology, fish could be recorded (Gerlotto et al., 1992). Under most conditions, in depths smaller than 10 m, vertical acoustics should be used with extreme care due to the high probability of avoidance behaviour.

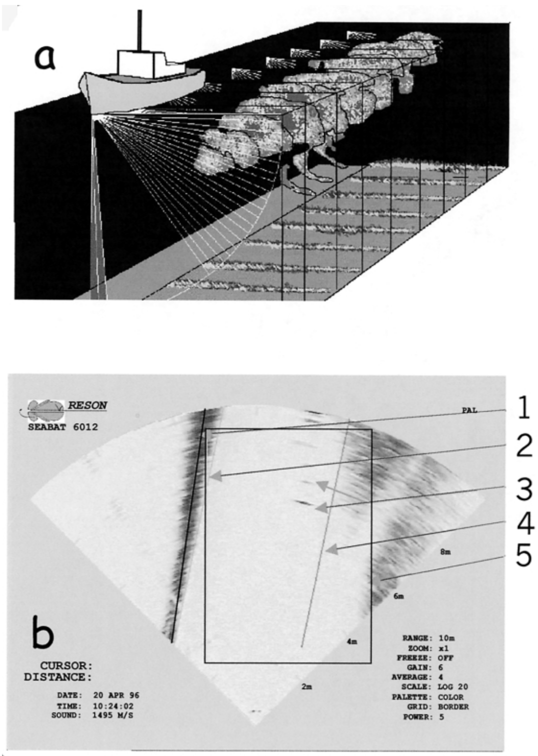


**Figure 1.** Description of the data collection system. (a) schema of use of the sonar. According to the objective, the sonar is directed from the vertical to the horizontal or from –45 to +45°. (b) video frame of an acoustic cross section during processing by the program SonarViewer. Dark traces near the sea surface, 6–10 m from the transducer and 1 m below the sea surface are fish echoes. Bottom depth is about 3.5 m. 1: bottom mean line; 2: bottom offset line; 3: fish targets; 4: surface offset line; 5: area of interest.

## 2.2. Advantages of MBS

The MBS, when used as a scanning sonar in the vertical plane (*figure 1a*), is an appropriate tool to use in shallow waters, from several points of view.

– Spatial description of echo sources. With a series of very thin beams, several problems related to multiple reflections are resolved: for instance, the reflection of the echo on the surface will not be mixed with the actual echo: eventually it reaches the transducer at such an angle that it will be plotted outside the original beam (usually observed above the surface line or below the bottom). The same phenomenon occurs with reflection of the bottom echo on the surface: the 'ghost echo' is observed outside the sampling area.

– Volume. For horizontal acoustics in shallow waters, the MBS resolves the extreme contradiction between the needs for a thin beam and a wide sampling volume. Adding a series of thin beams, as in multibeam sonar, allows a wide (even exhaustive, i.e. complete volumetric coverage, in the 3 dimensions) sampling volume and a long range (*figure 1a*). Another advantage is that the directivity diagram of the transducer is usually flat all along the global beam angle (i.e. 90, 120 or 180°). This and the exhaustiveness of water mass observation make this methodology suitable for echo counting, which is often preferable to echo integration when fish are highly scattered.

– Fish behaviour. The MBS may help to correct biases imposed by variable fish behaviour: fish may strongly avoid a vessel in shallow areas (Soria, 1994), but strong avoidance is limited in distance in most of the cases, at least when using a small craft. Fish typically begin to avoid an approaching vessel a few meters ahead, but avoidance rarely exceeds a few meters to the side of the vessel. Even in deeper zones (15 to 150 m depth) surveyed with a large research vessel, we observed that fish school avoidance is usually limited to less than 30 m horizontally (Soria et al., 1996). When observing to the side of the vessel, no (or very limited) bias due to avoidance has to be considered. The MBS also enables individual movements of fish to be observed and measured.

## 2.3. Limitations and disadvantages of MBS

Experiments using a MBS RESON SEABAT 6012 (Fernandes et al., 1998) allowed a listing of the major limitations of this kind of equipment.

– Noise. This is the most important disadvantage. The bottom echo is generally recorded by the side lobes and reverberates on all the beams, drawing a ring on the image. At distances longer than the bottom depth, a strong background noise appears, due to this side lobe effect and multiple paths of these bottom echoes. Practically, the echoes recorded there cannot be used for echo integration or TS measurement; their only use is for echo counting or morphological school measurements. The 3D echogram obtained using the software SBIViewer (Hamitouche-Djabou et al., 1999) on a sequence of images, shows most of the noise sources and limitations one may expect on a MBS data set (*figure 2*).

– Significance of the individual echoes. The 3D acoustics provides unique and invaluable information on school morphology, individual fish location, and spatial and dynamic behaviours, but echo energy is not easy to process, and even less to interpret: what is the meaning of a fish echo split into several beams, particularly when the fish size is much larger than any of these individual beams and presents a variety of incidence angles (which is important at high frequencies)?

– Data processing. The 3D reconstruction of a volume requires that the images be reshaped in order to correct the effect of pitch and roll. This makes necessary the operation of a motion sensor and the processing of all the information. At present, real time processing is problematic. Another limitation is the large amount of data that are provided by the equipment.

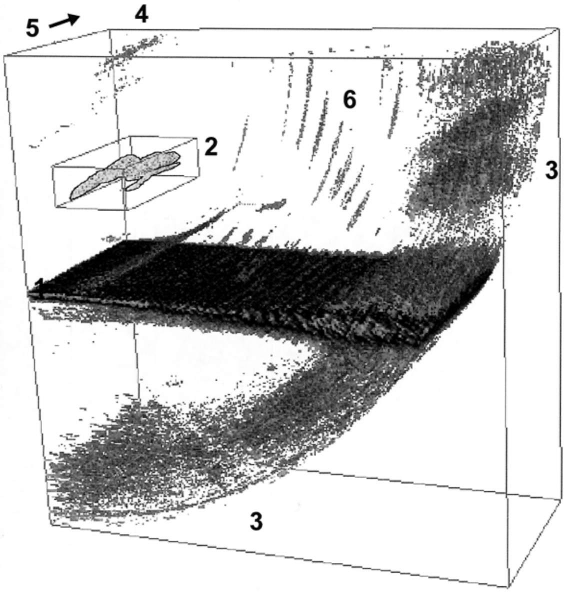


**Figure 2.** Typical 3D echogram obtained with the multibeam sonar. (1) bottom echo; (2) school echo; (3) background noise; (4) echo of the wake of a small craft; (5) location and direction of the transect; (6) acoustic interference with the vertical echo sounder.

## 2.4. Image analysis

Multibeam sonar data were collected for testing the prototype software and producing the present results, using a RESON SEABAT 6012 sonar. Each ping covers a total sector of 90°, divided into 60 beams of 1.5° (between beams) by 15° (perpendicular) each. The sonar operates at 455 kHz (20 kHz bandwidth) with a pulse duration of 0.06 ms and a ping rate adjustable according to the desirable operation range.

Two data sets were used to evaluate the methodology under different survey conditions. The first data set was collected in Cuba (Buenavista Bay, May, 1996), where the transducer was installed on a small boat, with the fan of beams normal to the vessel track. The sonar beams were directed vertically with the middle beam parallel to the sea surface (*figure 1*). Bottom and surface reverberations are observed as parallel lines moving in accordance to the vessel roll (Gerlotto et al., 1994; Soria et al., 1996).

The second data set was recorded during the AVITIS-98 survey in Greece (Thermaikos Gulf, April––May 1998) by utilising a similar Seabat sonar mounted on a pole on the starboard side of a vessel cruising at a relatively low speed (4 knots).

During both surveys the video output of the RESON sonar was recorded on commercial S-VHS VCRs, and later in the laboratory, selected video images were digitised at 8-bit resolution using a commercial PC grabber. The grabber has been calibrated for estimating the optimal settings (brightness and contrast), in order to avoid saturation during digitisation. The grey level of the image is proportional to the voltage of the echo, and its square is used as an index for describing the acoustic density of the encountered fish concentration. The grabbing frame rate was 7 frames·$s^{-1}$.

Software for sequential processing of the video frames has been developed to identify several fish aggregation forms, and extract parameters to assist classification or biomass estimation. *Figure 1b* demonstrates the operation of the SonarViewer software in a case where the multibeam transducer was installed in a vessel horizontal to the sea surface in very shallow waters (4 m). Although the surface reverberation line is not well developed, it can be estimated from the strong seabed trace. The pixel resolution of the image is about 2.25 cm (at a 10 m range), while along the acoustic axis the acoustic spatial resolution for the applied pulse width of 0.06 ms and a sound speed of 1 500 m·$s^{-1}$ is approximately 4.5 cm.

The user defines the bottom line and the bottom offset in the first image of the data set, as well as the surface offset, which are automatically adjusted in each new image according to a bottom recognition and tracking algorithm incorporated in the software. In order to exclude possible erroneous reverberations from the analysis, a square limiting the area of interest can be drawn. The square follows the movement of the bottom line each time the vessel rolls. This feature was built taking advantage of two phenomena: first, the bottom line is always observed in shallow water acoustics, and second, rolling is the only important movement that affects a vessel in shallow waters. Therefore, taking the bottom line movement into consideration allows for correction of the effect of vessel motion in the sequence of images, with no need for costly motion sensors.

## 3. RESULTS

Echo traces encountered in a video image (*figure 1*) can be analysed by plotting profiles along the crossing beam axis or perpendicular to the beams (*figure 3*) in order to evaluate the image characteristics in different directions. Along the acoustic axis, the acoustic resolution is very high (2.25 cm), due to the used pulse (0.06 ms) allowing the identification of probable single fish targets, between 7 and 8 m range from the transducer. TVG mode applied on this data set was $40 \times \log R$.

Perpendicular to the beams and from the bottom echo to the surface another profile is illustrated (*figure 3b*). The resolution in this direction is relatively low. At the distance where the fish is encountered (about 8 m from the transducer), and for a beam angle of 1.5°, the resolution will be about 21 cm. Therefore single fish echoes cannot be resolved in the profile.

Samples were extracted along the beam axis or perpendicular to a group of axes. All encountered schools show an oscillated acoustic index along their mean crossing beam axis index, with a peak-to-peak

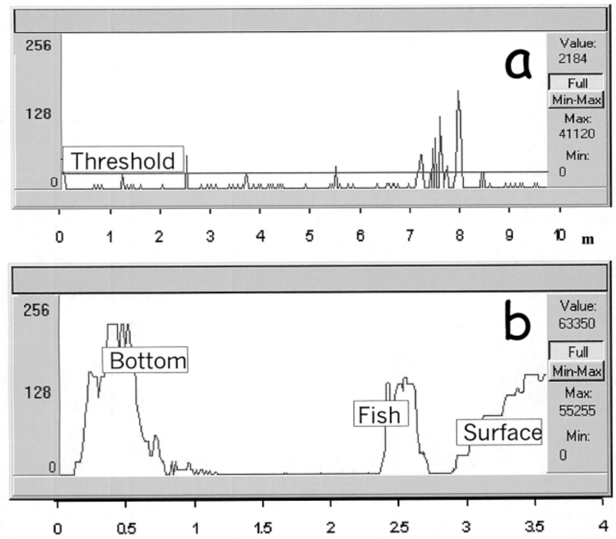


**Figure 3.** (a) Radial profile showing a group of fish 7–8 m from the transducer. Horizontal line delimits the used threshold. Distances measured in meters from the transducer, amplitude extracted from image grey value. (b) Profile perpendicular to the beams, crossing the bottom echo, the same group of fish as in 3a and the surface reverberation. According to their echoes the fish were located 2.0 m above the bottom.

range of about 25–50 % of their mean value. The spatial length between two maxima varies about 0.5–1.5 m.

The arithmetic mean of the background noise values of the 'low noise area' (i.e. area at distance < depth) is about 20 units of the acoustic index, whilst the equivalent level for the 'high noise area' (distance > depth) varies between 30 and 40. Maximum values vary in the range of 50 units. The variance of the measured values is proportional to the means. in the following processing a threshold of approximately 50 units is used for the school isolation from the background noise.

School descriptors have been extracted from 71 isolated schools, applying the SonarViewer software. The encountered variability of the descriptor values and their interrelations are shown by means of histograms and scatterplots in *figure 4*. The histograms show the typical variations of the descriptors, known from the 2-D studies. The volume distribution is exponential-like, showing that the volumes for more than 50 % of the schools are smaller than 250 $m^3$. A prediction of the school mean acoustic index based on the school volume in this preliminary analysis, explained more than 52 % of the variance.

The description of the spatio-temporal structure of the school is investigated by comparing the area vs. other school descriptors frame by frame. Schools are identified and accepted as such if their area in each cross-section is larger than 3 $m^2$ (*figure 5*). Most of the schools show a significant increase of their distance, indicating a mean school movement of 2 m per 90 frames perpendicular to the vessel (*figure 5*).

## 4. DISCUSSION AND CONCLUSION

### 4.1. Application of MBS to shallow waters

The first observation we can extract from this study is that MBS is able to provide information on both scattered and schooling fish. The background reverberation is low compared to the signal reflected by scattered fish or school aggregations. Scattered fish can be easily distinguished from the noise, and, in

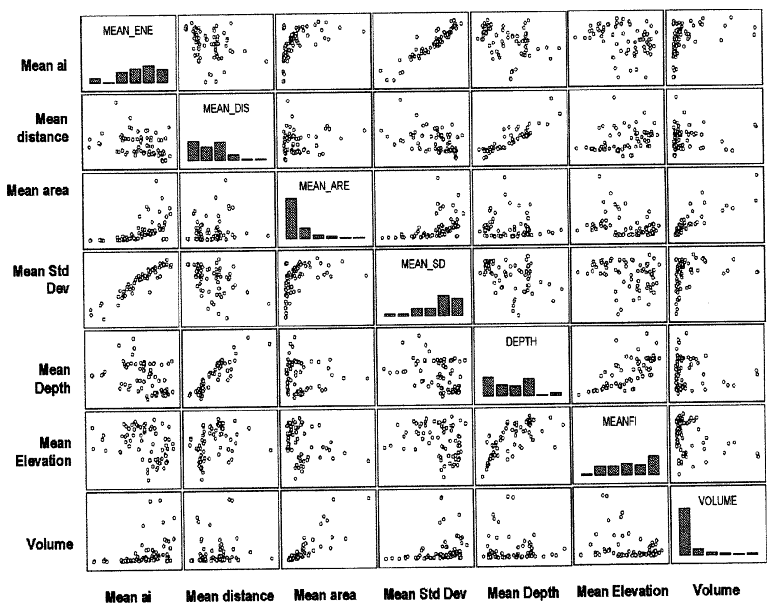


**Figure 4.** Histograms and scatterplots of extracted school parameters from 71 isolated fish schools. The school parameters have the following ranges, from the left to the right: mean acoustic index (0–255), mean distance from the transducer to the geometric centre of the school (0–50 m), mean cross section (0–100 $m^2$), mean value of the calculated standard deviation of acoustic index in each frame (0–50), mean depth of the geometric centre of the school (0–30 m), mean elevation (0–90°), and school volume (0–500 $m^3$).

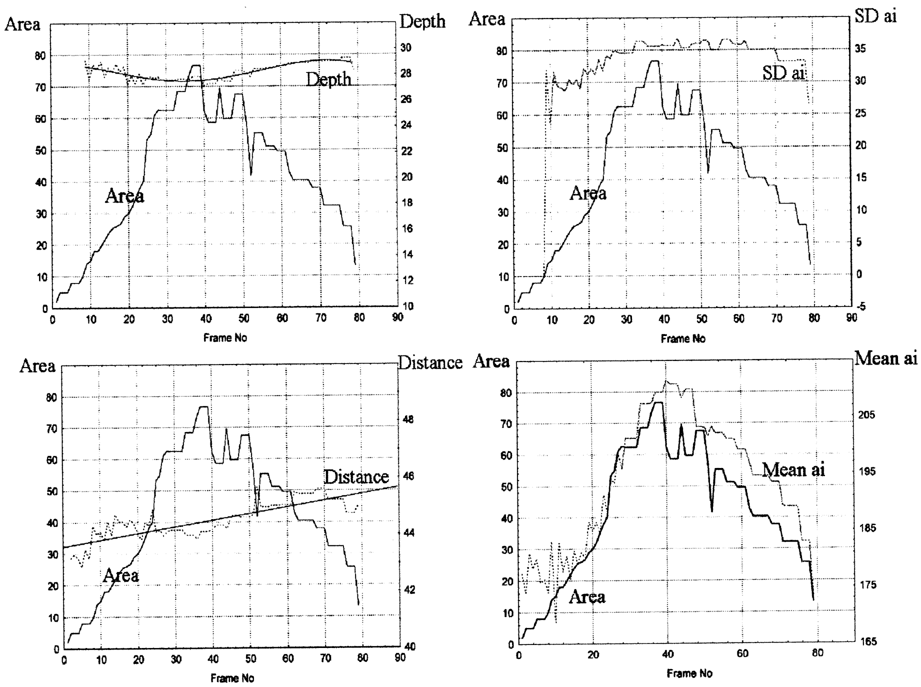


**Figure 5.** Four school parameters (depth, standard deviation of acoustic index, distance to the transducer and mean acoustic index) are plotted versus their video frame (right axis). In addition the cross section area of the school, observed in each frame is plotted (left axis), allowing the monitoring of the continuous change of the school shape (school ID: 74007).

most cases, surface reverberation does not cover fish echoes, even in shallow waters and close to the surface (*figure 3b*). Due to the very short pulse, each fish trace envelope in *figure 3a*, should be a multiple of the pulse length spatial representation. Schools encountered entirely or partially inside the 'far high noise area' probably provide descriptors affected by the different noise levels. However, the signal from most of the encountered schools is about 9–10 times stronger than the background reverberation in the noisy area, and therefore this bias is limited.

It is worth mentioning that the estimated school morphological descriptors (length, area, and volume), based on the 3D measurements, do not include as many side-cross-sections of small underestimated school-parts as those produced by the 2D analysis of the vertical echosounders. It is expected also that these descriptors, due to the narrow beams of the MBS, are less biased by increasing distance and therefore are much more appropriate to any classification or species recognition approach (Haralabous and Georgakarakos, 1996). One may note also that some evidence of school avoidance was observed with these data.

## 4.2. Definition of the ideal multibeam sonar

### *4.2.1. Frequency and pulse length*

In horizontal acoustics one of the important biases is related to the position of the fish in the beam axis (Kubecka, 1996), especially when high frequencies are used. This problem is serious, if we consider that usually the only parameter measured for echo characterisation is the voltage amplitude of the signal reverberated by the fish. Among the recent literature, very few works have used this echo duration. However, Burwen and Fleischman (1998), succeeded in using pulse width for species recognition in salmonids. These authors cite Ehrenberg and Johnston (1996, in Burwen and Fleischman, 1998), who evaluated the use of pulse width to separate fish by size groups. It appears that there is potential information in this dimension, which to date has been underexploited. Ehrenberg and Johnston (1996, in Burwen and Fleischman, 1998) give a more detailed equation, for an elliptic shape of the fish, as (equation 2):

$$d = \sqrt{l^2 \sin^2 \theta + w^2 \cos^2 \theta}$$

Where $d$ is the echo length on-axis, $l$ and $w$ respectively the fish (or swimbladder) length and width, $\theta$ the incident angle of the fish referred to a full side aspect. One potential way to resolve the problem of highly variable TS could be to take this echo length into consideration. This requires that the frequency be high in order to allow a short pulse length. If a pulse length can be set at (or less than) 0.1 ms, i.e. 15 cm length, it becomes possible to discriminate fish separated by 7.5 cm. If we consider with Medwin and Clay (1998) that a fish is an heterogeneous target, then its global echo will depend on its actual dimension. *Figure 6* gives the dimensions of the echo length (for $\tau$ = 0.06 ms) for the same 19.5 cm long fish (assumed width 3 cm) as studied by Kubecka (1996) at different tilt angles, calculated from equation (2). Considering these possibilities, and the fact that at short distances (i.e. less than 20–30 meters) absorption is not a

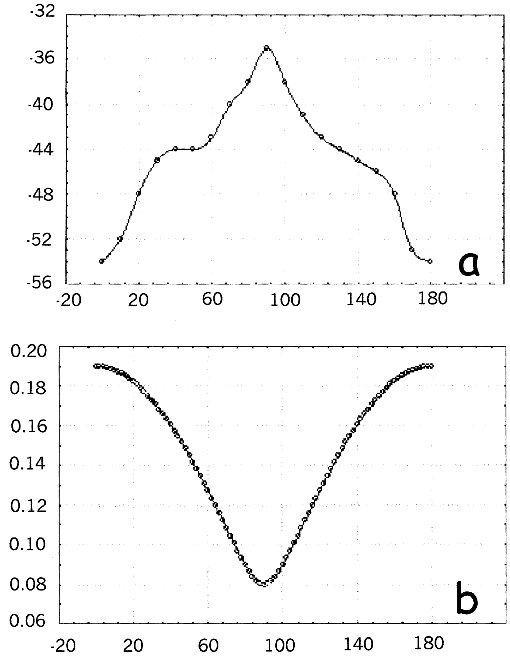


**Figure 6.** Effect of fish angle to beam axis. (a) target strength measurement (dB) for a fish with tilt angle 0°–180° to the beam axis (from Kubecka, 1996); (b) echo pulse duration (ms) of the same fish for the same angles.

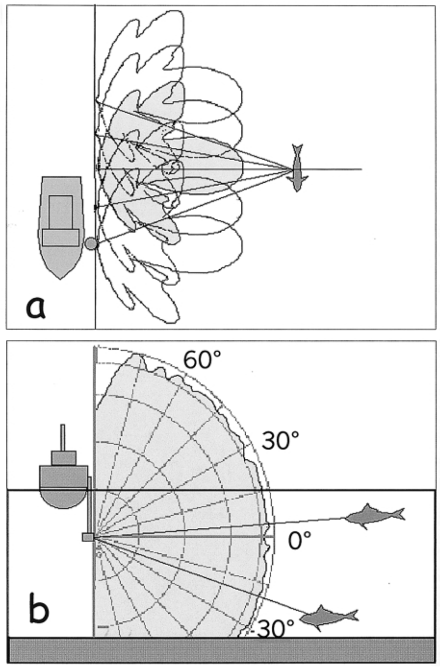


**Figure 7.** Schema presenting the effect of the directivity index in the 3 dimensions in fish target strength measurement. (a) diagram in the horizontal plan; the on-axis echo is obtained at least once in the ping series; (b) diagram in the vertical plan. On-axis echo is obtained at any angle of the fish.

limiting factor even in sea water, it is clear that the 'ideal' MBS should have the highest frequency and shortest pulse length possible.

### *4.2.2. Beam pattern*

Three points have to be considered for beam pattern choice.

– Beam angle. In the wide observation plan, the narrowest angle is required (but some solution to near field width must exist). This would have two effects. It allows to increase the precision of the 2D image received in a single transmission, and to maintain a good definition even with an increase in range. Although one could wish to use the thinnest beam angle, for practical reasons (number of data mainly), a compromise of 0.5° seems optimal. In the plane perpendicular to the scanning one, a narrow beam is also desirable depending on the objectives of the research. However, a too narrow beam would lead to a slight decrease of the sampling volume at high speeds. If the objective of the survey is to provide quasi exhaustive echo counting, the narrowest beam would be desirable, and 1 or 1.5° is the best setting. If the MBS is to be used to provide global biomass assessment, and to obtain usable TS values, then it may be preferable to have a rather wide beam, i.e. above 5°. Another possible drawback of too narrow beams in every directions to the determination of TS is that most fish would almost always appear in part inside the beam angle. This is not a problem in the plane of the multiple beams, although the echoes will be split into several neighbour beams. However it will not be possible to define whether the fish is on-axis or not. It is likely that to determine the axis position of fish, an even wider beam angle might be needed, and 10° or even 20° could be acceptable. Then, according to the high ratio between ping rate and vessel speed, practically all the targets will simultaneously be in the beam axis in the 3 dimensions: on the vertical plane, as the directivity diagram is practically flat, and in the horizontal plane in at least one of the pings (*figure 7*). Therefore the on axis TS measurement will be given by the maximum total echo value among the series of pings.

– Side lobes. If we need to consider the echo length as a usable data, this means that we would have to set a very low threshold. Burwen and Fleischman (1998) measure the echo width at 6, 12 and 18 dB below the maximum value of peak amplitude. They note that –6 dB is not well correlated with the fish length, while –12 dB is the best value. This is likely due to the signal-to-noise ratio, and we may assume that the best correlation will be possible with the lowest threshold. This requires a high signal-to-noise ratio. This is not often easy to obtain for MBS, where the bottom echo is reverberated in all the beams at distances larger than the depth. This means that for depths of 1 m, even though the system is able to observe the area at longer ranges, most of the volume will be rather noisy and not

**Table I.** Comparison between the optimal characteristics of a multibeam sonar and SEABAT 8125.

| Features | 'Optimal' sonar | SEABAT 8125 | |
|---|---|---|---|
| Power requirements | 12–24 V DC | 20–30 V DC, 2 A peak (provided by sonar processor); 110–220 V AC for the processor | |
| Sonar operating frequency | high frequency (≥ 400 kHz) | 455 kHz | |
| Receive narrow individual beam width | 0.5° | 0.50° at the centre beam | |
| Receive perpendicular beam width | 10–20° | 20° | |
| Transmit perpendicular beam width | 10–20° for transects<br>1–2° for behaviour observation | 1° or 20° adjustable (20° with FLS option) | |
| Number of narrow beams | ≥ 120 | 240 | |
| Sector coverage | minimum coverage 60° | transmit:<br>receive: | 130°<br>120° |
| Ping rate, full sector at 1 500 $m \cdot s^{-1}$ sound speed | ≥ 10 $ping \cdot s^{-1}$ | Range<br>5<br>10<br>15<br>20 | $ping \cdot s^{-1}$<br>40<br>31<br>22<br>16 |
| Range (m) | 2.5–50 | 2.5–120 | |
| Side lobes | –40 dB | –32 dB at present | |
| Settings | TVG set by the operator<br>pulse width ≤ 0.1 ms | TVG fully adjustable<br>pulse width from 0.011 to 0.29 ms | |
| Data processing | digital/video output | digital/video output | |
| Calibration | Built-in facilities | ? | |
| Near field | ≤ 1 m | 1.2 m (TX nearfield at 1° longer) | |
| General field use | Fully portable, input plugs for GPS and motion sensors | Not fully portable. Input plugs for GPS and motion sensors | |

always suitable for absolute signal measurements. A 40 dB difference between main lobe and side lobes is desirable.

– Number of beams. The optimal tool would allow sampling over a full 180°. However, in shallow waters the immediate neighbourhood of the vessel is highly biased by fish behaviour and may not be worth surveying. Observing a single side of the route may be sufficient in most applications, and avoiding transmitting vertically could help decrease the 'bottom noise ring' effect.

#### *4.2.3. Other features*

– Type of data. The ideal output data is digital data. This requirement means that the system must be able to handle large quantities of data. For example, for an ideal system with sampling units as short as the half pulse length, i.e. around 2–5 cm, and a beam angle of 0.5° then for a single beam and a range of 20–30 m, each ping will produce between 500 and 1 000 sampling units. For 100 beams and a ping rate of 10 $s^{-1}$, 0.5 to 1 million data per second will be possible. Another alternative is to use image analysis. This method degrades the quality of the results, as video images are much less precise than digital data. Nevertheless it gives precise enough results and above all may be applied to any MBS which fulfils the main conditions we listed here. The major advantage of video analyses is that the raw data are very easy to record and store, and processing is done using the simple existing tools of image analysis. Digital image recorders are currently available, which do not degrade the analogue output of the MBS. Finally we may consider that in a near future the storage and processing capabilities of PCs, as well as the data filtering possibilities will largely resolve these problems.

– Material. Most of the research developed in shallow waters require a small vessel, which often means fully portable equipment (sonar, computer, etc.). A 12–24 volt DC powered system is required. It is also desirable that all the ancillary data (GPS, pitch and roll, etc.) be built-in and automatically received and processed by the sonar or the computer, considering the difficulty or impossibility to operate easily these system independently in a small craft.

– Calibration. It is an extremely important and difficult part of the methodology. Simmonds et al. (1998) developed a method for calibrating a 455 kHz multibeam sonar using a 12.7 mm diameter tungsten carbide sphere. Nevertheless, some built-in calibration facilities would be a great help.

– Data processing. This is also an important part of the methodology. Most of the image analysis methods would apply for spatial description, echo counting, and other routine analyses. But many acoustic measurements would require some reconstruction of the fish echo, which will be split into several portions in the different beams and pings. It is likely that TS measurements will not be possible on individual single echoes from an individual beam.

At present, no MBS is specifically designed for fisheries acoustics research. Our team has been operating a RESON SEABAT 6012 since 1992 during two European projects. This experience, shared with the company, allowed us to experiment and comment on some of the existing systems. The most adapted is the RESON SEABAT 8125, which fulfils most of the requirements listed here. The main characteristics of this sonar are presented in *table I*. One can see that most of the optimal features are already fulfilled in this existing sonar system. In synthesis, the limiting factors in application of multibeam sonar to shallow waters are not technological. The most needed technological improvements for application to fisheries acoustics are likely the homogeneity of individual beam characteristics (calibration procedure). The main limiting factors are thought to be methodological, mostly from two points of view:

– evaluation of the significance of the echoes and design of methods for TS and abundance estimates adapted to shallow waters, horizontal acoustics and multibeam technology;

– design of methods for data processing and analysis.

Three dimensioned data processing and imaging has already be explored for deeper waters (Mayer et al., 1998; Fernandes et al., 1998). The main results are that apart from the need for an effective data processing system, no particular difficulty lies in this field, especially for morphological analysis of fish schools. When studying individual fish, it is likely that many more constraints will arise, in particular for clarifying the meaning of the echoes and for discriminating these echoes from background noise and reflections.

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