Ices Journal of Marine Science
May 2008, Volume 65 (4): Pages 645-655
http://dx.doi.org/10.1093/icesjms/fsn051

The new fisheries multibeam echosounder ME70: description and expected contribution to fisheries research

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Abstract:

Recently, Simrad in collaboration with Ifremer developed a calibrated, multibeam, vertical echosounder (ME70) for fisheries research. We describe its capabilities and technical limitations. The ME70 has up to 45 beams with distinct frequencies in the range 70–120 kHz, spanning at most 150°. All beams are stabilized in vessel roll and pitch. It has reduced side-lobe levels, up to –70 dB (two-way) instead of the –25 dB (one-way) of conventional systems. We outline research areas for which the ME70 might provide new types of information and hence lead to novel insights. We illustrate the potential contributions with datasets collected in the English Channel and on the continental-shelf break of the Bay of Biscay. Finally, future research and developments using the new system are outlined.

Keywords: abundance, acoustics, behaviour, three-dimensional

1. Introduction

The use of acoustic methods for the estimation of fish abundance has a history of more than a half century (see review in Fernandes et al. 2002 for their use within the ICES area). Since the early 1950's, substantial progress has been made at all stages of the process, from the measurement instruments to signal extraction and interpretation (Simmonds and MacLennan, 2005). Vertically oriented single beam echosounders operating at frequencies ranging from 38 to 200 kHz are most commonly used for fish abundance estimation. Quantitative estimates were made possible by the introduction of standardised calibration protocols (Foote *et al.*, 1987).

Several physical factors influence the usefulness of acoustic methods for abundance estimation. Beam width in combination with depth, but also pulse duration and bottom topography determines the extent of the dead zone near the sea floor for which no information is available (Ona and Mitson, 1996). The acoustical observations of different species are affected to varying degrees by this dead zone. For example, a large proportion of cod, haddock and redfish are thought to reside in the dead zone during most of the time (Aglen *et al.*, 1999). The detection range for single targets depends on the echosounder performance, fish target strength, and ambient and vessel noise levels, and thus may differ between vessels (Mitson and Knudsen, 2003). As beam width determines the diameter of the volume or surface insonified (sampled) at a given depth, for vertical echosounders the backscattering strengths from fish schools smaller than this diameter will be underestimated and their dimensions will be overestimated; thus the bias in evaluating small schools increases with depth (Diner, 2001, 2007). For oblique beans the backscattering strength decreases with increasing angle (Melvin *et al.*, 2003; Zedel *et al.*, 2005).

The acoustic backscattering properties of individual fish result from the interplay between physical and biological factors. They are a function of signal frequency and depend on the morphology of the species, its schooling behaviour as well as on the individual's orientation and body shape and size (Misund, 1997) but also their physiological state (Ona, 2003). Fish reactions to the noise and light emitted by the surveying vessel has been found to bias abundance estimates (Olsen *et al.*, 1983; Misund, 1997). This may be due to changes in fish tilt angle as they dive in front of the survey vessel (Gerlotto and Fréon, 1992; Handegard and Tjøstheim, 2005; Cutter Jr and Demer, 2007).

In addition to the standard method of abundance and biomass estimation by echo-integration, in combination with fishing hauls carried out for species and size identification (see description in Simmonds and MacLennan, 2005), acoustic information has also been used to study schooling behaviour (ICES, 2000) and the potential impact of fishing on spatial distribution patterns (Wilson *et al.*, 2003). For this, standard protocols for extracting morphological school descriptors from vertical echosounders have been proposed (ICES, 2000; Reid *et al.*, 2000). These provide school characteristics in two-dimensions (depth and along ship), as no information perpendicular to the survey track is available. Thus neither horizontal (athwartship) avoidance reactions nor their expected impact on school morphology can be studied using single beam echosounders. To overcome this limitation, horizontal and vertical scanning multibeam sonars have been employed (Misund and Aglen, 1992; Gerlotto *et al.*, 1999; Soria *et al.*, 2003). Multibeam sonars have also increasingly been used to study natural fish behaviour, including the determination of swimming speeds, aggregation dynamics and spatial school characteristics (Misund and Aglen, 1992; Mayer *et al.*, 2002; Gerlotto and Paramo, 2003; Brehmer *et al.*, 2006) but also predator-prey interactions (Benoit-Bird *et al.*, 2004).

To propose an instrument that might be useable in situations with predominantly schools of small size where beam width is a strongly limiting factor, Ifremer and Simrad, a manufacturer of acoustic instruments, joined forces in 2001. They developed the first calibrated multibeam echosounder (ME70) for fisheries research which was installed on the French fisheries research vessel Thalassa in the summer of 2005. Thalassa is a modern noise reduced fisheries vessel (Mitson and Knudsen, 2003).

The ME70 has two principal operation modes for observing organisms in the water column (fisheries research mode) and for bathymetry and habitat classification (bathymetry mode). The aim of this manuscript is to describe the fisheries research mode of the ME70, to illustrate its expected contribution to fisheries research and present some preliminary results. Section two provides a detailed technical description of the new system and a discussion of its advantages and limitations. Section three illustrates the expected contributions of the ME70, which have been grouped under three headings in relationship to the limitations of acoustic measurements: schools of small size, mixed-species associations and individual and school behaviour. Areas for which the ME70 will not offer any improvements are not considered. Conclusions and directions for future research are proposed in the last section.

2. Characteristics of ME70 in fisheries research mode

The ME70 is a calibrated multibeam echosounder for obtaining quantitative information on organisms in the water column (Andersen *et al.*, 2006). It can be configured with up to 45 beams spanning at most 150 degrees, the athwartship centre angle of the fan can be adjusted from +45° to –45° degrees. Each beam has a unique frequency in the range 70 to 120 kHz and a unique steering angle, except for one special configuration where all beams have the same steering angle. The spread of steering angles through the fan is either linearly spaced or optimised for side lobes reduction. Beam width can be selected from 2.2° to 20° for the central beam, the width of the other beams are then adjusted depending on frequency and steering angle. In addition, there are two special beams, called reference beams, which can be configured separately and freely in terms of frequency, steering angle and beam width, for example for comparison with single beam echosounders or for increasing the sampling volume by adding them as wide beams (20° opening) steered at 50°. All beams can be operated as split-beams. Beam emission occurs in groups of one to four beams. As single-beam vertical echosounders used in fisheries research, it provides volume backscattering strength (S_v) values and target strength (TS) data when the beams are configured as split-beams.

The innovative design of the ME70 is based on a matrix of 800 individually controlled transducer elements functioning both at transmission and reception. The challenges of real-time processing of huge amounts of data were surmounted and the resulting tool is promising and allows a high degree of user-controlled flexibility. The ME70's matrix transducer offers up to –70 dB sidelobes (2-way) compared to about –25 dB (one way) for "T" array geometries of conventional multibeam systems (Figure 1a). Hence, the ME70 is a multifrequency echosounder capable of collecting data throughout the whole fan, in particular outside the spherical volume (Figure 1b) where sea-floor backscattering through the side-lobes (Figure 1a) strongly limits fish detection in conventional multibeam systems. All beams are stabilized with respect to vessel's roll and pitch to maintain the steering angles of all beams fixed between transmission and reception.

The ME70 has numerous configuration options, each is a trade-off between several factors, and their choice will depend on the objectives of the study (Table 1). Figure 2 shows a typical beam configuration ('V' configuration). Figure 2a provides a schematic view of the athwartship beam distribution; the along ship distribution is shown in Figure 2b. The steering angle and frequency of each beam in this configuration is shown in Figure 2c. When selecting a beam configuration, the following points need to be considered:

1. Selection of the number of beams and pulse length. As each beam of the fan has a distinct frequency, the number of beams depends on the selected pulse length and frequency bandwidth, and vice-versa. With the maximum frequency bandwidth ranging from 70 to 120 kHz and the maximum number of beams being 45, the minimum pulse length available is 2048 μs in the case of a continuous wave signal (CW). If the number of beams is reduced to 21, the minimum pulse length is reduced to 1024 μs.
2. Selection of the number of beams to be transmitted simultaneously. The options range from 1 to 4 beams per transmission group. The choice affects the detection range as the source level is 12 dB higher in the case of separate transmissions (group of 1) compared to transmissions by groups of 4. The extent of the blind zone underneath the vessel is also affected as it is inversely proportional to the number of frequencies per group (see rule in Table 1).
3. Selection of the frequency distribution pattern. The frequency distribution in the fan can be set up in different ways. Three different options have been evaluated. To maximize the detection range, the 'V' configuration has the lowest frequency in the centre and the highest frequencies in the most steered beams. To maximize the angular resolution, the 'Λ' configuration has the highest frequencies in the centre and the lowest frequencies in the outer beams. To explore species discrimination using multi-frequency analysis, in the 'I' configuration all the frequencies (beams) are pointing in the same direction (not necessarily vertical). The choice between 'V' and 'Λ' configurations will be guided by the objectives of the scientific survey in terms of angular resolution (possibility of narrower beam opening at the vertical for the 'Λ' configuration) and detection range (longer range at the vertical with the 'V' configuration). When narrow angular resolution and long detection range are both required at the vertical, the 'Λ' configuration combined with a reduced number of frequencies per transmission group can be a suitable option but at the detriment of the length of the blind zone underneath the vessel which is increased.
4. Selecting the sampling volume (fan width) perpendicular to the vessel track. Three series of parameters require determination, these relate to the prevailing role of the centred beam in the definition of the fan's characteristics: 1) along and athwart ship beam width of the centre beam, 2)

athwart ship beam spacing and 3) along and athwart ship steering angle of the centre beam. In technical terms, an appropriate weighting of all cells in the array is automatically calculated when the beam width of the centred beam is set to a given value. As a consequence, the beam widths of all other beams are a function of the frequency distribution, the beam steering angles and this pre-calculated weighting. However, it is somewhat restrictive to describe the fan's characteristics only through the sampled volume and, remembering the originality of the ME70 in terms of side-lobe reduction, more valuable information can be collected with a given beam configuration when the resulting side-lobe levels are included in the consideration. The results shown in Figure 3 emphasize that it can be judicious to slightly lower the angular resolution to increase data quality and reduce noise outside the spherical volume. As beam width increases from 2.3° in Figure 3a to 2.8° in Figure 3b, the corresponding weighting on the array consequently reduces the side lobe level for each beam and leads to reduced artefacts outside the spherical volume in the outer beams (-33° steering angle in Figure 3).

The high available angular resolution (minimum 2.2° for a beam centred on 120 kHz) and reduced side-lobes of the ME70 can reduce the dead zone compared to traditional echosounders with 7° or 11° beam widths. Unfortunately, the ME70 currently suffers from a limitation in beam forming, which affects data collected in a fixed layer equal to 75 cm above the sea floor visible in all subplots of Figure 3. Despite this limitation, the improved bottom resolution with the ME70 for an uneven sea floor is evident when comparing data obtained with a EK60 (7°, 120 kHz; Figure 4a) with data from the central beam of the ME70 (2.8°, 117 kHz; Figure 4b).

In addition to collecting information with the multi-beam fan, the ME70 offers the possibility to duplicate data collected with traditional vertical echosounders. For this, two additional reference beams can be used, whose frequency, beam opening and steering angle can be set freely by the user. Only the pulse length remains the same as in the fan beams. The two reference beams are always transmitted after the fan beams to reduce frequency leakage with the fan beams. Although the reference beams increase the extent of the blind zone underneath the vessel by about one or two pulse lengths (depending on whether they are in the same or separate emission groups), they can be useful for comparisons with conventional vertical echo-sounders operating at the same time.

Once a particular configuration has been selected, the system can be run with default system gains automatically calculated from stored values. However, it is strongly recommended to calibrate each configuration. The ME70 calibration procedure is similar to that for other echosounders (Foote *et al*. 1997), particularly for the EK60 echosounders. To adjust the nominal gain set by default, the two parameters "gain adjustment" and "Sa correction adjustment" must be measured for each beam. If we define the gain as the ratio of the intensity measured in a given beam to the one for an omni-directional transducer, the first parameter concerns the offset between the theoretical gain and the one measured for the calibration sphere. The second parameter corresponds to the offset between the theoretical contribution of the shape of the pulse on the integrated response of the sphere and the measured one. A typical view of the fan in the calibration interface is presented in Figure 5a for a configuration with 19 beams and a sequence of 150 to 350 sphere TS measurements per beam. The resulting calibration parameters are presented in Figure 5b. Calibration results for a beam configuration with only 15 beams and a wider athwartship sector are also presented, including standard deviations for the gain adjustment estimates. The calibration sphere used for this test was the 25 mm diameter sphere made from tungsten carbide with 6% cobalt binder provided with the ME70. Due to the low weight of this sphere, an additional weight was suspended below the sphere to stabilize the calibration target, but this requires careful attention when calibrating the outer beams to avoid detecting the echo from the weight. Future calibrations may use larger and heavier spheres described in Foote (2006). Their use alleviates the need for an additional weight and their high target strength values improve detections in a noisy environment. A disadvantage is that two instead of one sphere are needed to calibrate the full fan, which will require further developments of the calibration procedure.

To take fullest advantage of the ME70 and the five frequency EK60s installed on Thalassa, all are configured and controlled using HERMES software, specifically designed for the purpose. HERMES stores the data from all echosounders (ME70 and EK60s) in a single file using the HAC standard format detailed in ICES (2005).

3. Potential research applications of ME70

Some of the challenges in the acoustic method identified in the introduction may be addressed with data from the ME70. This will be illustrated with two data sets. Data from herring schools were collected in March 2006, in shallow waters in the English channel (Table 2). Data were also collected from mixed species with mainly small shoals in March 2007 on the continental shelf break of the Bay of Biscay. The ME70 configurations used for each data set are given in Table 2. MOVIES software (Berger *et al.*, 2005) was used to perform echo-integration and extraction of shoal parameters.

3.1. Schools and shoals of small size

The size, e.g. horizontal diameter, of single or multispecies pelagic fish schools depends on species, season, time of day, depth and geographic location (Scalabrin and Massé, 1993; Soria *et al.*, 2003). Individual schools are often grouped into clusters (Petitgas, 2003). In the Bay of Biscay, nearest neighbour horizontal distances between pelagic schools within clusters range from 400 to 3300 m (Petitgas, 2003), while horizontal school length is often around 10 m. Little is known about school width (perpendicular to survey track), but investigations with vertical scanning multibeam sonar have shown that pelagic fish schools seem to be elongated, with school length up to twice the width for *Sardinella aurita* (Gerlotto and Paramo, 2003). Based on geometrical considerations and simulations Diner (2001) proposed an algorithm for correcting school length measurements which are increasingly overestimated with depth due to the increased sample volume. The correction is valid if the true school length is at least 1.5 times the sampled beam diameter, (e.g., school length must be ≥12m at 100 m depth for a 4.5° beam width and ≥18 m long if beam width is 7°). Thus a small school is one whose length is less than 1.5 times the beam diameter at the given depth. Hence the definition of small depends both on the depth of the school and the beam width. Similar, non negligible depth effects might exist for abundance estimates based on echo integration due to negatively biased backscattering cross sections of small schools (as defined above) at greater depths (Diner, 2007).

The reduced beam angles (minimum 2.2°) of the ME70 are expected to provide several benefits including improved estimates of school length and backscattering cross section estimates for smaller schools, i.e. those too small for the conventional 7° or 11° beams. Of course using a smaller beam width only reduces the number of schools that fit the aforementioned definition of “small”. For the mixed species data, in the central beam of the ME70 (beam opening 4.3°), about 30% of encountered shoals were smaller than 1.5 the beam width at the depth of the shoal. For the 7° single beam measurements at 70kHz, the corresponding figure is about 65%. In that data set the majority of shoals were found near the sea floor at depths around 200m.

Based on the use of several beams, an additional estimate of school width and thus the complete school geometry is obtained. The mixed example shows the effect of increasing the spatial resolution on observed school structure (Figure 6). This example also illustrates the effect of beam stabilisation for the ME70. While the image from the EK60 is smeared perpendicular to the survey track, the image reconstructed from the three central beams of the ME70 is much sharper.

A drawback of using small beam widths is that the ping rate might have to be increased or the vessel slowed down to maintain an overlap between subsequent samples. The effect of non-overlapping along-track samples appears for the herring school situated in shallow water (Figure 7). For large schools, unsampled areas along the survey track are not a problem, while for small schools this might lead to biased estimates of school morphology parameters.

3.2. Mixed species associations

Pelagic species form mixed or closely located schools in many shelf seas. For example in the Bay of Biscay anchovy (*Engraulis encrasicolus*), horse mackerel (*Trachurus trachurus*), mackerel (*Scomber scombrus*), sprat (*Sprattus sprattus*) and pilchard (*Sardina pilchardus*) are commonly found together in varying species combinations related to geographic location (Massé, 1996). Tropical pelagic species are also often found in mixed schools with individuals of similar size belonging to different species occurring together (Fréon, 1984). Similar observations have been made in the Bay of Biscay where small horse-mackerel were caught together with large anchovy of similar sizes (V. Trenkel, unpublished data).

Numerous attempts have been made to identify monospecific schools based on morphological (school length, perimeter, density, etc.) and contextual information (location, depth, time of day, etc.) (Scalabrin *et al.*, 1996; LeFeuvre *et al.*, 2000; Lawson *et al.*, 2001). Although this approach has allowed species classifications for particular data sets, its general applicability seems to be hampered by the fact that school morphology varies with environmental characteristics (Scalabrin and Massé, 1993; Muiño *et al.*, 2003; Soria *et al.*, 2003) fish size (Iglesias *et al.*, 2003) and maturation state (Mackinson, 1999), perhaps even more so than species.

At least two alternative strategies have been proposed to advance acoustic species classification: inclusion of the third dimension for morphological school description (Fernandes *et al.*, 2002) and use of multifrequency information (see review in Misund 1997). So far, broad groups (plankton, fish with and without swim bladders) have been distinguished successfully based on the differential sound scattering over a range of discrete echosounder frequencies (e.g. 18, 38, 120 and 200 kHz) (Korneliussen and Ona, 2003) or using the response difference between 38 and 120 kHz (Woodd-Walker *et al.*, 2003).

The ME70 is not only multi-beam (multi-angle) but also multi-frequency in the range 70-120 kHz. This frequency range may be useful for collecting information needed for species identification. Multifrequency data from the vertical and steered beams are from a single transducer array and do not suffer from the common problem of horizontally displaced transducers not sampling exactly the same scene (Korneliussen and Ona, 2002; Korneliussen *et al.*, accepted).Tank measurements have shown that anchovy and sardine TS values do not vary much between 70 and 120 kHz (flat frequency response), although the absolute levels differ between the two species (Conti and Demer, 2003). This might be a general result. Simmonds and Armstrong (1990) found that is was possible to distinguish between herring, mackerel and gadoids in the range 27 to 54 kHz although they did not investigate higher frequencies. From the above cited work we might expect the frequency response of many species to be flat over the range covered by the ME70 (70-120 kHz), which would be favourable for abundance estimation with the ME70, but ineffective for species classification. Thus, the new information provided by the ME70 might be most effective if used in combination with data over a wider range of frequencies from single beam echosounders. A subset (3 nautical miles) of the mixed species data set illustrates the potential of combining information form the ME70 and EK60s (Figure 8). The example includes both diffuse and dense shoals. The frequency response derived from EK60 data could be combined with information from the ME70 on fish density distributions within shoals and shoal morphology. The 3D shape of the flat layer on the right hand side of figure 8, though unidentified, may be indicative of a single species. However, frequency responses, particularly in shallow waters, are often rather variable due to the reduced overlap of the volume sampled by the different frequency EK60's which is caused by the position of the transducers on the ship hull (maximum distance 1 m on Thalassa) but also variable beam widths (when considering 18 kHz). In deeper waters, the difference in steering angle of the transducers (maximum 1° on Thalassa) can also lead to some variability in the frequency response curve. The roll and pitch stabilised 3D image obtained with the ME70 will be of great use to determine which echoes were well sampled by all frequencies and consequently for filtering the data to obtain more accurate frequency response curves. In addition, improved *in situ* single target measurements, due to smaller beamwidths and simultaneous use of different frequencies as proposed by Demer et al. (1999) might also help species identification.

3.3. Individual and school behaviour

The potential impact of avoidance behaviour on abundance estimates derived from acoustic measurements has raised concern for a long time (Olsen *et al.*, 1983; Gerlotto and Fréon, 1992; Vabø *et al.*, 2002). Reactions to an approaching survey vessel have been observed using multibeam echosounders (Gerlotto *et al.*, 1999; Gerlotto and Paramo, 2003; Soria *et al.*, 2003). In contrast, Fernandes *et al.* (2000) based on comparison between acoustic measurements from the survey vessel Scotia (built to ICES reduced noise standards) and an autonomous underwater vehicles, concluded that herring did not seem to avoid noise reduced survey vessels. However, Ona *et al*. (2007) found that a noise reduced survey vessel induced stronger vertical diving reactions of herring compared to a conventional survey vessel. Using a conventional survey vessel, Gerlotto and Paramo (2003) found that fish schools near a vessel track, most likely round sardinella, were nearly twice as long as wide, while those located about 30 m from the track line had similar width and length. Vertical reactions (i.e. diving responses) have also been observed for anchovetta (Gerlotto and Fréon, 1992), herring (Vabø *et al.*, 2002) and cod (Handegard and Tjøstheim, 2005).

The ME70 may likewise contribute to behavioural studies of individual fish and schools, be it natural or in reaction to the vessel. As previously demonstrated, three-dimensional measures of fish schools as a function of horizontal distance from the vessel track allow behaviours to be visualised and quantified. Consider again the herring school example (Figure 7). The school might have reacted to the vessel as individuals on the vessel track were lower than those to the side (Figure 7a). Furthermore, as the vessel progressed over the school, the depths of individuals were increased (Figure 7b). As all ME70 beams can be configured as split-beam, the movements of individuals along and across track, i.e. within and across beams, can be measured and tracked. Studies of fish movements might facilitate progress on characterisation of fish reaction behaviour and the remote identification of species or age groups. For example, Kang *et al*. (2006) found that the variability of swimming angles within walleye pollock schools was related to the dominant age group present in the school.

The configuration of steering angles of the ME70 fan is somewhat flexible, ranging from all beams (with different frequencies) pointing into the same direction ('I' configuration, see Characteristics of ME70 in fisheries research mode), to each beam having a separate angle, but also a separate frequency. A configuration with multiple 'I's, i.e. the same range of frequencies at different steering angles is not possible, but multiple slightly tilted 'I' (with non-overlapping frequency ranges) are possible. Such a configuration would allow to explore whether changes in tilt angle as a result of avoidance reactions lead to changes in backscattering which differ between steering angles, as derived theoretically by Cutter Jr and Demer (2007). In their simulation study these authors found that side-ways and diving responses of fish schools were visible as a difference in backscattering strength between central and steered beams (>30°), however in their study all beams had the same frequency. As the ME70 beams have different frequencies, the overlaying frequential response might somewhat blur the picture.

Additionally, the potential biases in abundance estimates due to school reactions can be more directly evaluated. The NASC values calculated for the shoals in Figure 7 were found to be at least four times as high in the outer beams (athwartship angle ±20°) compared to the more central beams.

Trawl efficiency is another topic that might be might be evaluated from ME70 observations either directly such as those illustrated in figure 9 which shows a passage of the survey vessel over a fishing trawl in action. Individual fish are visible in the trawl opening (Figure 9b).

4. The next steps

As shown in this paper, the calibrated multibeam echosounder ME70 is a powerful complement to other sampling devices, such as traditional multifrequency echosounders. To achieve its maximum potential, a few technical challenges must be surmounted. For example, reliable bottom detection must be achieved in all beams, a problem particularly acute for the outer beams where the non-oblique incidence angle reduces bottom contrast. Furthermore, tools for visualising the ME70 data in 2, 3 and 4-D are essential (Mayer *et al.*, 2002).

The dependency of Sv and TS on both frequency and incidence angle need further exploration and quantification. Hazen and Horne (2003), found that tilt angle variation was the most important factor for changes in simulated TS values, even more important than body length or depth. The importance of tilt angle variations was confirmed by experimental work on krill (McGehee *et al.*, 1998).

The currently ME70 provides 3D views for fish schools. However future research is needed to develop pertinent descriptors for the amorphous shapes of fish schools which are not well described by spherical or cylindrical bodies (Gerlotto and Paramo, 2003); thus school width and length metrics are not sufficient to capture the entire geometry.

Algorithms must be developed to connect shoals and individual fish across EK60 and the ME70 beams. Improved precision for tracking of individuals pursuing the approach proposed by Handegard (2007), who uses several types of information simultaneously (phase angles, echo intensity, ranges and times) will provide further insights into fish behaviour and its effects on biomass estimation. It will be necessary to track individuals not only within a beam but also across beams, which might be complicated by the potential impact of observation angle and frequency on TS values.

The ME70 is operational for studying the pelagic zone. A noise problem currently limits its application in the layer extending 75 cm above the sea floor. This problem may be surmounted with enhanced beam forming techniques and faster computers for real-time processing.

Acknowledgement

We would like to thank Simrad for a fruitful collaboration. Noel Diner is thanked for initiating the development of the ME70. The development of the ME70 was supported by the European funding scheme IFOP. We are grateful to Niels Olav Handegard, David Demer, Chris Wilson and an anonymous referee for useful comments on a previous version of the manuscript.

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Tables

Table 1 : Parameter choices for multibeam fisheries echosounder ME70 and resulting technical performance.

	Input parameters		Technical performance
Characteristics of multibeam fan	Frequency bandwidth	70 - 120 kHz	Determines minimum pulse length
	Number of beams	3 – 45	Trade-off between frequency bandwidth, number of beams and pulse length
	Type of signal	CW or LFM*	
	Pulse length	64 - 5120 µs	
	Number of frequencies emitted per group	1 – 4	Range detection is longer when fewer frequencies are transmitted together Blind zone extend ≈ $cT/2\left(\left[N_{fan}/N_{freq}\right]+1\right)$ *c*: sound velocity, *T:* pulse length; N_{Fan}: number of beams fan; N_{Freq}: number of frequencies emitted per group. $[\ ]$ denotes the integer part of the quantity in brackets.
	Order of transmission	Increasing or decreasing steering angles	Determines the shape of the blind zone
Distribution in frequency	Shape	V configuration	Longer detection range in centered beams. Beam opening narrower in outer beams than in centered beams.
		Λ configuration	Longer detection range in outer beams. Beam opening narrower in centered beams than in outer beams.
		I configuration	Suitable for multi-frequency analysis
	Frequency spacing	Linear	Suitable for I configuration
		Optimized	Reduces leakage between frequencies
Distribution in space	Along ship beam width for the centred beam	2.2 - 20°	Determines the along ship and athwart ship sampled volume (beyond blind zone)
	Athwart ship beam width at the centred beam	2.2 - 20° maximum	Realisable beam opening range depends on frequency.
	Along ship steering of the fan	0° default (5° max.)	
	Athwart ship steering of the fan	0° default (45° max.)	
	Beam spacing	Linear (in °)	
		Optimized (-1 to – 4 dB)	

*CW: continuous wave; LFM: linear frequency modulated

Table 2. Details of example data sets used in this study and ME70 configuration used.

Data set	Start	Depth range (m)	Distance (nautical miles)	Vessel speed (knots)	Number of beams	frequency setup	beam width (°)	analysis threshold (dB)
herring school	25/02/2006 4:30	30	2	4.5	17	V ±40°	5 central 4 outer	-60 dB
mixed species	03/03 2007 14-18:00	80-200	15	~6	15	V ± 25°	4.2 central 3.3 outer	- 60 or - 80 dB

Figures

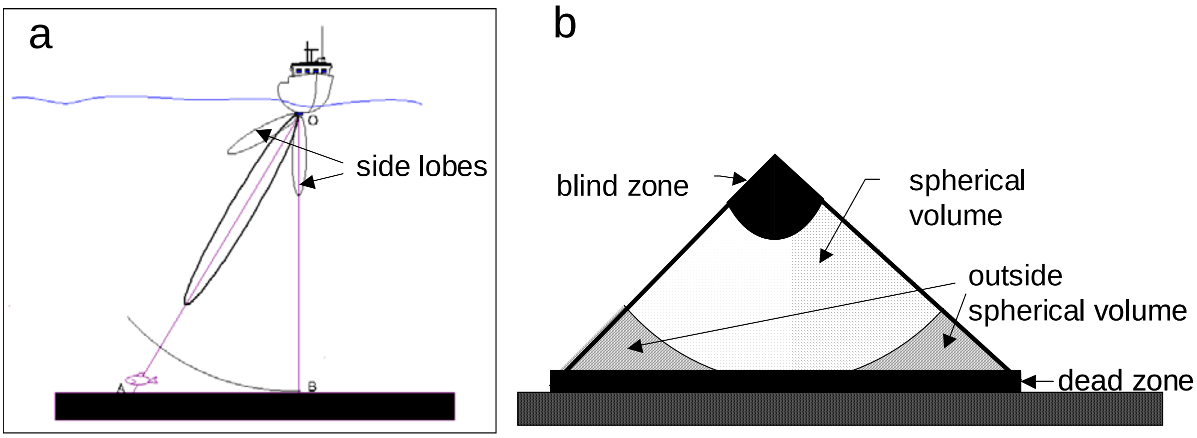


Figure 1. Definition of acoustical sampling volumes. a) outer beam with side lobes; beam detection of A is polluted by bottom detection through side lobe at point B; b) definition of sampling volumes of multibeam echosounder.

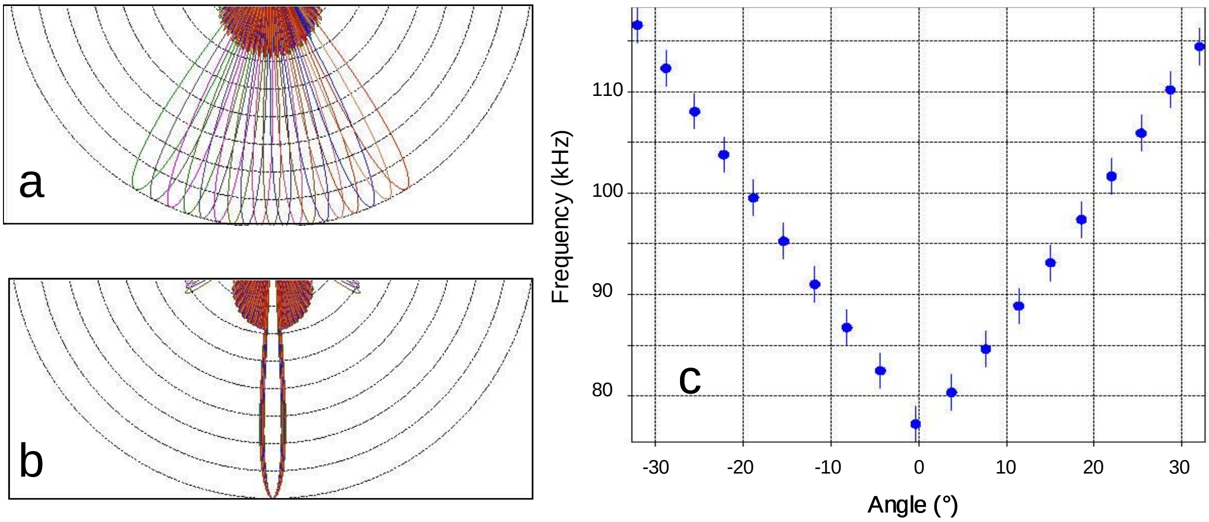


Figure 2. Schematic view of beam patterns of ME70. a) frontal view of multibeam fan; b) across track view of multibeam fan; c) frequencies and angular directions of beams in ‘V’ configuration. Vertical bars indicate frequency band width for each beam.

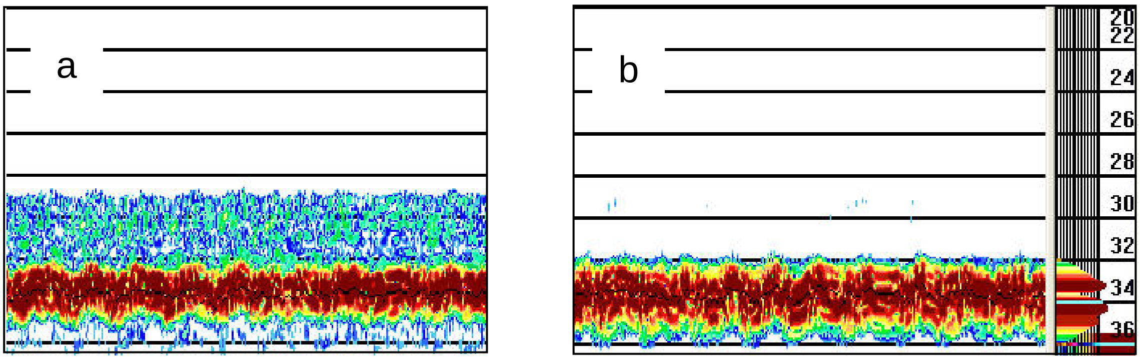
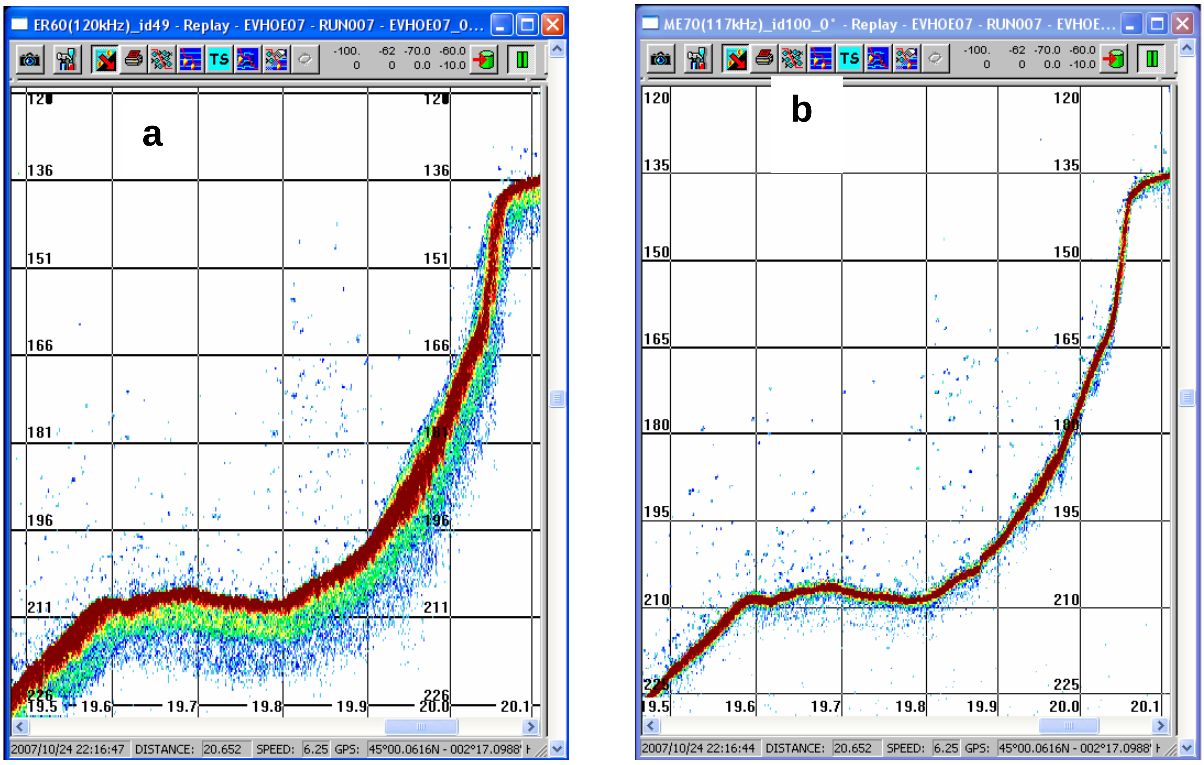


Figure 3. Impact of beam width and side lobes on sea-floor backscattering outside the spherical volume for a beam steered at –33°. a) Optimal beam width of 2.3° (one-way) obtained with the ‘Λ’ configuration, b) 2.8° beam width. Echograms are displayed with non-calibrated *Sv* data and a visualization threshold of –65 dB (using calibration results in Figure 5b, the threshold after calibration is expected to correspond to about -63 dB).



ER60(120kHz)_id49 - Replay - EVHOE07 - RUN007 - EVHOE07_0...

2007/10/24 22:16:47 DISTANCE: 20.652 SPEED: 6.25 GPS: 45°00.0616N - 002°17.0988'

ME70(117kHz)_id100_0° - Replay - EVHOE07 - RUN007 - EVHOE...

2007/10/24 22:16:44 DISTANCE: 20.652 SPEED: 6.25 GPS: 45°00.0616N - 002°17.0988'

Figure 4 : Dead zone for uneven sea-bed. a) ER60 (120 kHz, 7°), b) ME70 centered beam (117 kHz, 2.8° beam width); visualization threshold -62 dB.

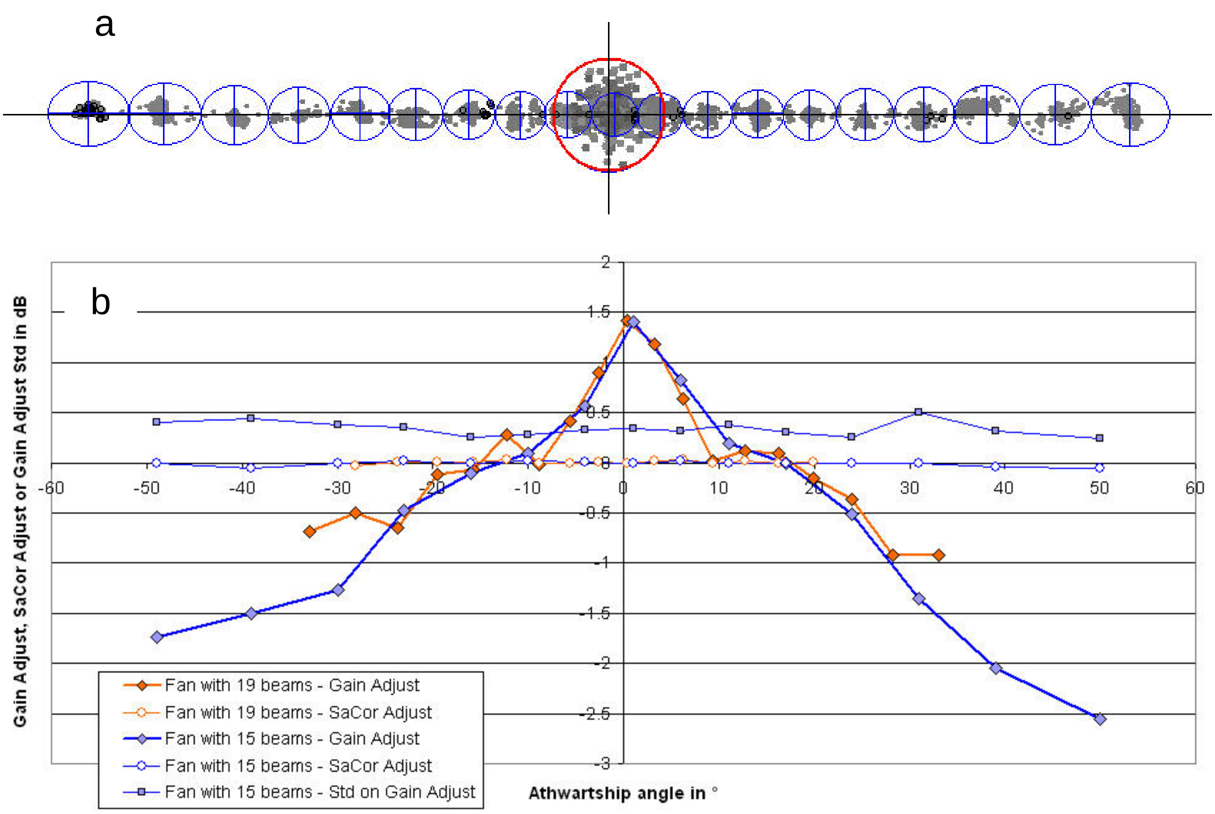


Figure 5. Calibration of ME70 two ‘Λ’ configurations. The first configuration has 19 beams, a 65° athwartship sampling volume and a 2.8° (one-way) beam width at the vertical, and the second configuration has 15 beams, a 100° athwartship sampling volume and a 5° beam width at the vertical. a) Spatial distribution of hits in the fan with 19 beams; b) Calibration parameters.

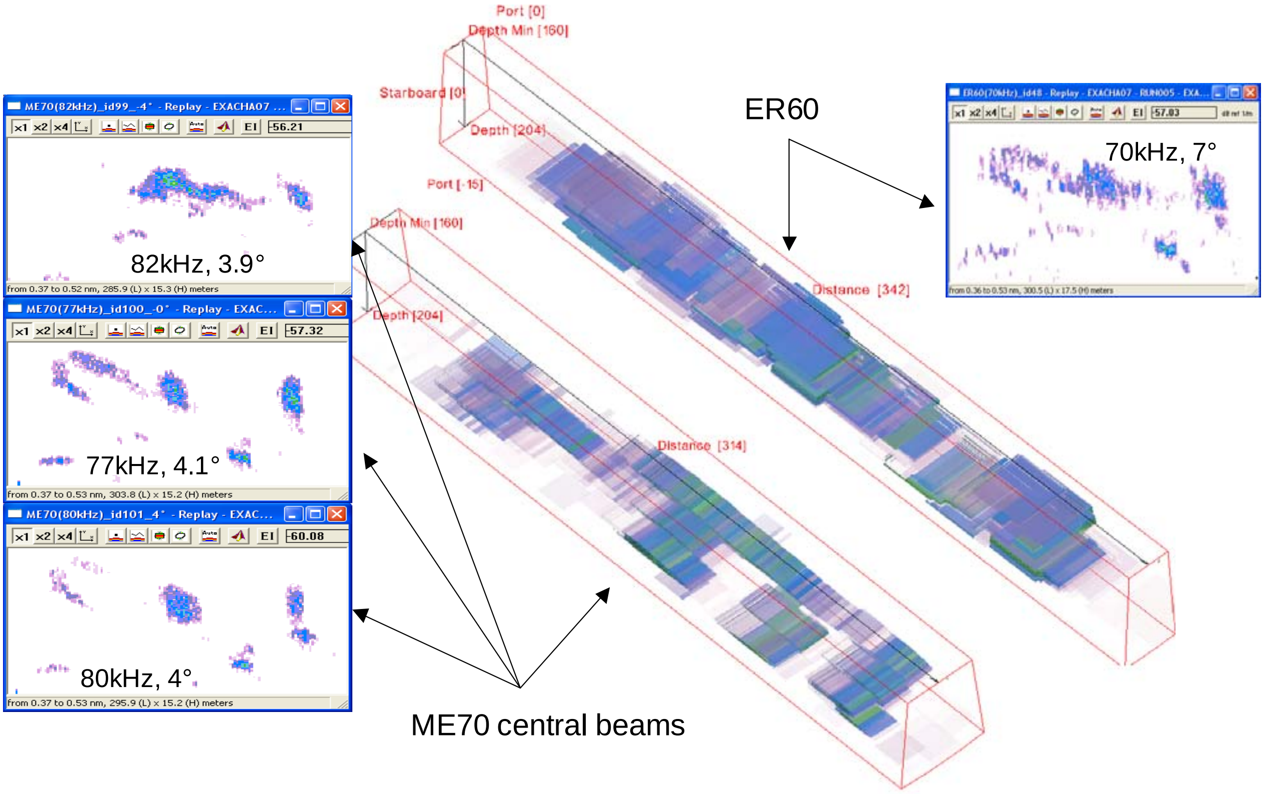


Figure 6. Single beam views and projected 2D view for three central beams of ME70 compared to ER60 (70 kHz) results for school in mixed species data set. Units on 2D views are in m.

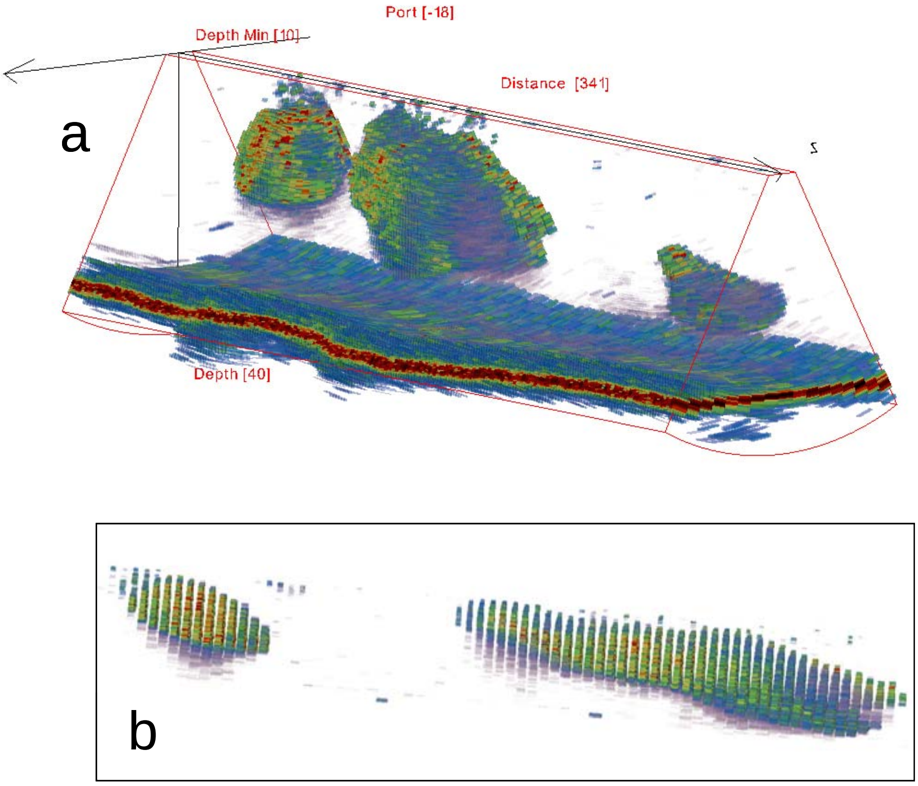


Figure 7. Herring schools. a) 3D view; b) Lateral view of the 3D school. Direction of travel from left to right in both figures. Black axes represent coordination system.

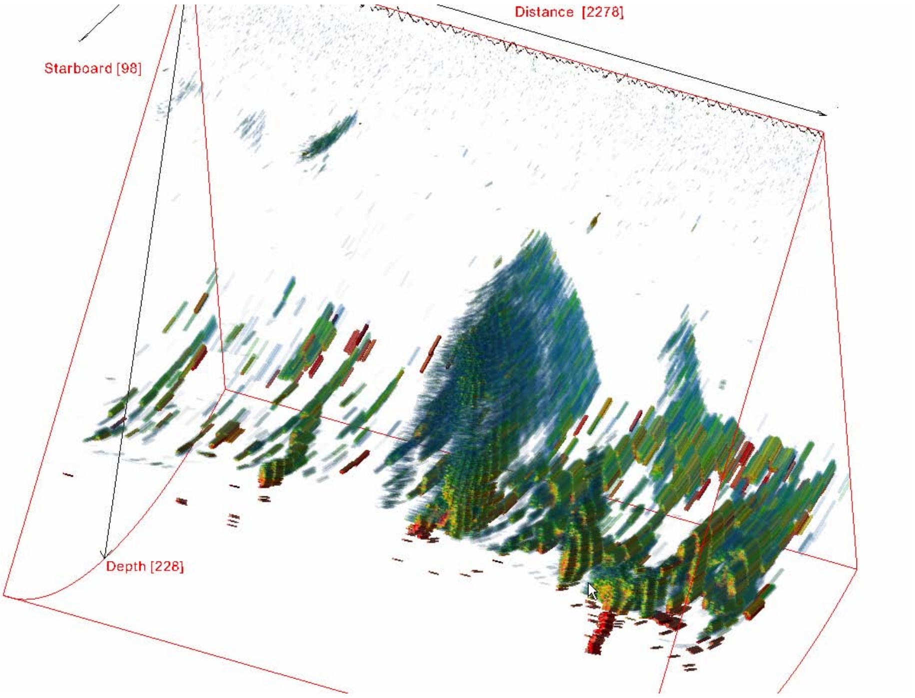


Figure 8. 3D view of mixed shoals of mackerel, horse-mackerel and other species in mixed species data set.

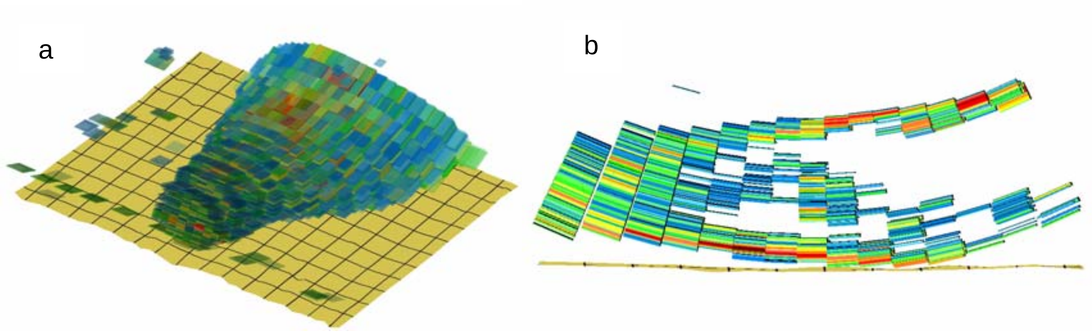


Figure 9. Acoustic image of commercial pelagic trawl crossed by survey vessel a) 3D view, b) lateral view.