# Combining multibeam-sonar and multifrequency-echosounder data: examples of the analysis and imaging of large euphausiid schools

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The first high-resolution, quantitative, multibeam sonar (Simrad MS70) ever developed was mounted in a keel of RV "G. O. Sars" with port-orientated beams. Each ping samples a volume of 60° horizontally × 45° vertically with 500 beams, which is often enough to insonify a complete school of fish or zooplankton. The large amount of resulting data is efficiently preprocessed with automatic, real-time detections of school candidates; these are accepted or rejected during post-processing. The system was used on the continental shelf near the Subantarctic island of South Georgia to study Antarctic krill (*Euphausia superba*), and some of the detected schools were immediately sampled with a six-frequency echosounder (Simrad EK60), then trawled with various nets to verify the target species and their size composition. For schools acoustically categorized as euphausiids, data from the two acoustic systems were used to estimate the school morphometrics and the krill size distributions. The principal objectives of this study were to explore the potential of combining data from a multibeam sonar, multifrequency echosounders, and nets, and to describe the efficient processing methods and software that facilitate the multi-instrument analyses. Three-dimensional morphometrics based on the MS70 data were consistent with corresponding two-dimensional morphometrics based on the echosounder data and could be used to improve the acoustic classifications of taxa or species. Additionally, automatic preprocessing and integration of data from different sources into the same user interface allowed efficient exploration and interpretation of all the acoustic data.

**Keywords:** acoustics, acoustic inversion, Simrad EK60, Simrad MS70, three-dimensional sonar.

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## Introduction

Echo integration (EI) of data from single-beam echosounders is the most common method of fish-abundance estimation (MacLennan, 1990). This technique is limited to calibrated observations inside the vertical beam (Figure 1) and is not effective for surveying schools residing close to the sea surface. Therefore, the new RV "G. O. Sars" was fitted with a custom-made, four-dimensional (*x*, *y*, *z*, and time), multibeam sonar (Simrad MS70). The sonar can be used in conjunction with the multifrequency echosounders, but the enormous amount of data resulting from both systems, particularly the sonar, requires a versatile, fast, and accurate post-processing system.

Abundance estimations from EI of echosounder data require accurate species identification (ID) and relationships between the integrated volume-backscattering coefficients ($s_a$) and target strength ($TS$) in the vertical plane (i.e. dorsal aspect) vs. animal length, for each target species. When applied to data from sonars and multibeam echosounders, EI also requires accurate models of $TS$ for any angle of incidence vs. animal size.

Target validation is difficult, because the sonar samples different volumes from those sampled by the echosounders and nets. Consequently, school measurements made by the two acoustic systems are not temporally and spatially coincident. Schools being measured should therefore ideally not change position much between the sonar and echosounder measurements. In this respect, schools of Antarctic krill (*Euphausia superba*) are ideal targets.

Krill size composition can be estimated, though with some uncertainty, from multifrequency data and krill-scattering models (Demer and Conti, 2005). It can be estimated with the post-processing large-scale surveying system (LSSS; Korneliussen *et al*., 2006; MAREC, Bergen, Norway), which compares favourably (Korneliussen *et al*., 2007) with the same algorithms implemented in MOVIES+ (Marchalot, 1998).

Species, and their size composition, can also be identified with direct sampling methods. Trawls and nets are selective (e.g. because of filtering and clogging), and the targeted animals often avoid the trawl gear. Consequently, several types of net are needed to sample effectively all the species and their size composition in the survey volume.

Towards estimating abundances from sonar and multibeam-echosounder data, this paper focuses on the challenges of acoustic-species ID and size-composition estimation. First, some three-dimensional metrics are calculated from four-dimensional

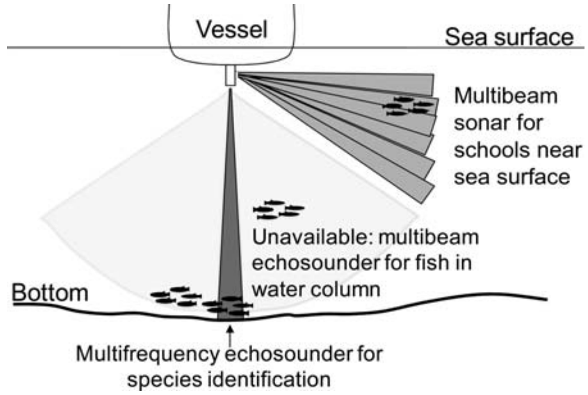


**Figure 1.** Measurements of key ecosystem components with the MS70 sonar and the EK60 echosounders. The gap between the two measurement systems could be filled by a Simrad ME70 multibeam echosounder.

data from krill schools. These three-dimensional metrics are then compared with two-dimensional metrics derived from single-beam echosounders, and net samples, from the same schools.

The sonar and echosounder data are combined in LSSS for post-processing that is both fast and reliable enough to be used during operational surveys. The goal is an improved understanding of school structure and dynamics, and ultimately more accurate abundance estimations of fish and zooplankton stocks that are completely or partially unobservable with echosounders.

## Methods

### Example survey

Data were collected north of the Subantarctic island of South Georgia (Figure 2b) in the austral summer, during January and February 2008. When schools were detected, they were circled by the ship for sonar observations from all lateral aspects. Then, the ship passed directly over the schools for multifrequency-echosounder observations. The latter data were used for acoustic-species ID and size-composition estimation. Finally, the species composition and concomitant size composition were verified by net sampling.

### Net sampling

Various nets were used in sequence to catch a wide range of species and size compositions at the same location to identify the acoustic scatterers. A large macroplankton trawl was deployed to sample krill and amphipods. It had a 36-m$^2$ opening (6 m vertical), and the entire length consisted of a 3-mm meshed net (Melle *et al.*, 2006). A multisampler was mounted at the rear of this trawl (Engås *et al.*, 1997), with five separate codends that allowed depth-stratified sampling during the tow. The towing speed with this net was 2.5 knots.

A larger macroplankton trawl, with a vertical opening of 14 m, was also used. It had variable mesh sizes in the front part of the trawl and 6-mm stretched mesh in the rear section. The towing speed with this net was also 2.5 knots.

An Åkra midwater trawl with a large codend was used primarily to sample fish. This trawl can also catch large krill (30–50 mm) effectively, if there are large quantities, but it does not catch smaller krill (10–20 mm) or amphipods of a similar size effectively. The Åkra midwater trawl had a circumference of 539 m. It was used with 750 kg weights, 7.5 m$^2$ doors manufactured by Egersund Trawl, sweeps of 160 m, and a 60-mm mesh bag. The typical towing speed was 3.5 knots.

### Sonar and echosounder sampling

Echosounder data were collected at 18, 38, 70, 120, 200, and 333 kHz, respectively. The echosounder transducers were mounted on a retractable keel, in an arrangement for optimal horizontal overlapping of the beams. All the transducers (Simrad) had nominal 7° beam widths (−3 dB), except for the 18 kHz transducer, which had a beam width of 11°. Compensations were made for the alongship horizontal offset of the transducers and the total system delay. During data collection, the faces of all the transducers were situated 3 m below the ship's hull and 9 m below the sea surface. The transmitting power for each frequency was set according to Korneliussen *et al.* (2008) to avoid cavitation and non-linear acoustic effects (Shooter *et al.*, 1974; Tichy *et al.*, 2003; Pedersen, 2007). For all frequencies, the pulse duration was set at 1.024 ms. The pulse rate was adjusted to avoid multiple echoes from the bottom, but was typically set at 1 Hz.

The echosounders were calibrated at South Georgia according to methods described by Foote *et al.* (1987). Vessel movements were monitored (Seatex MRU 5), and time, geographic position, heave, roll, pitch, and yaw were logged to the EK60 raw-data file. The unthresholded acoustic data were collected and processed according to recommendations made by Korneliussen *et al.* (2008), to ensure optimal data quality.

The sonar transducer was mounted in the same keel, with port-orientated beams. Its 500 beams covered a volume of 60° horizontally × 45° vertically. The sonar was operated in continuous-wave mode, with pulse duration of 2 ms and a data collection range of 400 m. The resulting depth range of the observations was 10–200 m. The sonar transmitted in the frequency bandwidth of 75–112 kHz, but used narrow sub-bands for each fan. The fan aiming downwards at 45° relative to the sea surface transmitted at 112 kHz; the frequency for each adjacent fan beam transmitted at sequentially lower frequencies until the 20th fan beam, aiming at 0° towards the sea surface, transmitted at 75 kHz. Four fan beams transmitted simultaneously (i.e. 112 kHz at 45°, 113.9 kHz at 47.5°, 115.7 kHz at 50°, and 117.6 kHz at 52.5° transmitted concurrently, followed by the next four, etc.). Therefore, all pulses with 2 ms duration were transmitted during 10 ms. The beam widths were between 3° and 4°, varying vertically with the frequency. The first side lobe was −35 dB relative to the main lobe vertically, and −25 dB horizontally. Using data from the MRU, the sonar automatically compensated for roll of up to 10°. The sonar pings were synchronized with those of the echosounder, typically at a frequency of 0.5 Hz. The sonar was calibrated in Norwegian waters following Ona *et al.* (2007), using 75- and 84-mm diameter spheres made from tungsten carbide and 6% cobalt binder.

### Echosounder data processing

The echosounder data were compensated for heave and roll and processed with the following steps in LSSS for acoustic IDs and size composition estimations:

(i) Remove noise spikes from pings of unsynchronized acoustic instruments;

(ii) Correct data vertically for echosounder-system delays;

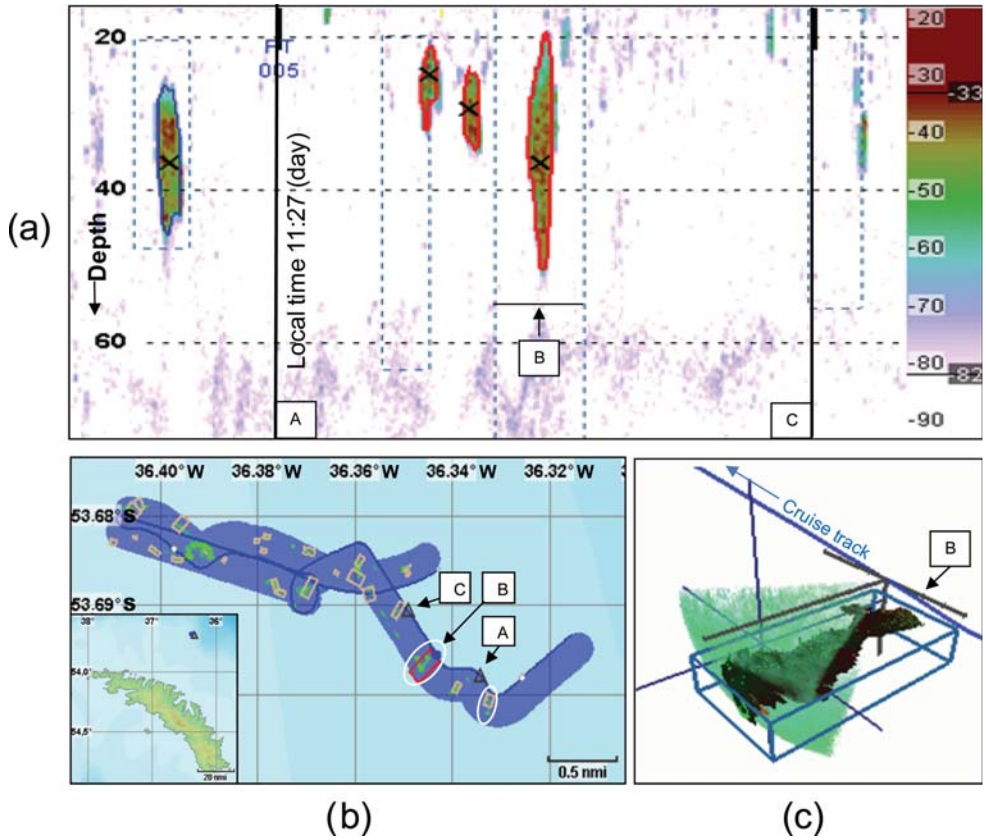


**Figure 2.** (a) A 38-kHz echogram indicating the start of trawling (A), the centre of a box enclosing a krill school (B), and the end of trawling (C). (b) Observation area relative to South Georgia showing the cruise track (thin blue line), the area covered by the MS70 sonar (wide lighter-blue line), the school candidates suggested by the PROMUS module of LSSS (green spots), and the schools accepted by the user (rectangles). (c) One school and its boundary box visualized in three-dimensions (*x*, *y*, *z*).

(iii) Correct data horizontally for alongship transducer positions;

(iv) Estimate the range to the seabed from the data at all frequencies;

(v) Smooth the data above the detected seabed with a filter with a Gaussian kernel of dimensions 8 m wide × 0.5 m deep;

(vi) Smooth the data from below the detected seabed with the same kernel. By separating steps (v) and (vi), the detected seabed is not smoothed;

(vii) Estimate the noise using data from each ping recorded long after the bottom echo (if such data exist);

(viii) Correct the data for the estimated noise;

(ix) Detect the schools by contouring −64 dB in the echogram derived from the average volume-backscattering strength ($S_v$) at 38, 70, 120, and 200 kHz. Accept as a school if the length of the closed contour is >20 m, the height is >5 m, and the vertical cross-sectional area is >50 m$^2$;

(x) Smooth inside the school (with a Gaussian kernel 100 m wide × 10 m deep);

(xi) Categorize data to taxa or species based on a ground-truthed training process (Korneliussen and Ona, 2003); and

(xii) Estimate the size composition of zooplankton using a zooplankton-inversion module (more details in the next section). Candidate zooplankton categories currently in LSSS are "plankton", "unknown", and "resonant_at_18 kHz".

## Estimation of zooplankton size

The optimized framework for the estimation of zooplankton size is described in detail in Fernandes *et al.* (2006). The same algorithms were implemented in LSSS. Inversions of scattering models with multifrequency $S_v$ provided estimates of standard length 2 ($L_{S2}$; Morris *et al.*, 1988). The zooplankton-inversion module reduced the spatial resolution of the $S_v$ data to small volumes 5 pings long × 20 samples deep, or 25 m for a pulse repetition rate of 1 Hz × 4 m for a pulse duration of 1.024 ms.

Zooplankton size composition was estimated using four zooplankton-scattering models (Table 1). The initial 23-element, zooplankton-size vector (Table 1) was iteratively refined through the inversions, resulting in fine resolutions at the size of maximum abundance. The iterations continued until the finest resolution was achieved, or all the elements remained unchanged between successive iterations, or the maximum number of iterations had been completed (inversion settings in Table 1). Only $S_v > -90$ dB from 18 to 200 kHz were used in the inversions.

Inputting measured volume-backscattering coefficients, $s_v^{\mathrm{meas}}$, at *N* frequencies, a scattering model was used to estimate the backscattering cross sections $\sigma_{\mathrm{bs}}(f, a)$ for one species at frequency *f* and

**Table 1.** Scatter models, parameter values, and inversion-algorithm settings.

| Model or parameter | Value or value range |
|---|---|
| High-pass, fluid, prolate spheroid (Stanton, 1989) | $g = 1.043$; $h = 1.05$; $L/r = 5$ |
| Hard-shelled gaseous sphere (Stanton *et al.*, 1994) | $R = 0.5$ |
| Gaseous sphere (Stanton *et al.*, 1994) | $g = 0.0012 \times (1 + 0.1 \times z)$; $h = 0.22$ |
| Fluid, bent cylinder (Stanton *et al.*, 1993, 1994) | $R = 0.058$; $s = 0.1$; $\beta_D = 10$ |
| High-pass, fluid prolate spheroid (copepods) size vector[a] | 0.3[b] − 8 (mm) |
| Hard-shelled, gaseous sphere (pteropods) size vector[a] | 0.3[b] − 8 (mm) |
| Gaseous sphere (siphonophores) size vector[a] | 0.3[b] – 8 (mm) |
| Fluid, bent cylinder (euphausiids) size vector[a] | 7.5[b] – 65 (mm) |
| Levenberg–Marquardt factor $L$[c] | $10^{-3}$ |
| Minimum residual error for stopping size-vector iterations | 0.001[d] |
| Maximum residual error for accepting solution | 0.2 |

$g$, sound-speed contrast; $h$, density contrast; $L$, length; $r$, radius; $R$, reflection coefficient; $z$, depth; $s$, s.d. of length; $\beta_D$, length-to-mean-width ratio.
[a]Size vector has 23 elements. Each size is either an equivalent spherical or cylindrical radii.
[b]The minimum size is constrained by ka > 0.1, a condition for model validity (Stanton *et al.*, 1993).
[c]Lawson and Hanson (1974).
[d]Iteration also stops if the size vector has gained a resolution of 0.1 mm.

equivalent radius $a$, resulting in estimates of volume-backscattering coefficients, $s_v^{\mathrm{calc}}$ (Holliday, 1977). The residual error,

$$\mathrm{err} = \left\| s_v^{\mathrm{meas}} - s_v^{\mathrm{calc}} \right\| = \sqrt{\sum_j \left( s_{v,j}^{\mathrm{meas}} - s_{v,j}^{\mathrm{calc}} \right)^2}, \tag{1}$$

was calculated for each pixel, for each scattering model. The model that gave the smallest residual error was allocated to that pixel, if err was less than a threshold.

### Estimating school boundaries

The MS70 data did not require processing for seabed detection, or spike and noise removal. The sonar data were processed with the automatic school-candidate detection algorithm where $S_v > -55$ dB at depths $<150$ m (Figure 2b). This automatic school detection indicates to the user where to look for potential schools. During the subsequent "semi-manual" school detection, a seed voxel, which the user deems to be inside the school, was selected for "growing" a school. Seeds had to be between 15 and 100 m deep and have $S_v$ of between −50 and −30 dB, although these values could be changed by the user. If the seed passed these detection criteria, the school was "grown" by testing the voxels closest in space and time. If they also passed the criteria, were not already part of the school, and were within 10 pings of the seed (i.e. detected schools can consist of samples of up to 21 pings), they were added to the school. These procedures continued for the neighbours of each added voxel until no further samples could be added. The outer extent of the school samples, including the volume covered by the beam and sample widths, was denoted the "uncorrected bounding box". The corrected bounding box only contained the sample centres.

### Estimating school morphometrics

The relative frequency response, calculated from the multifrequency-echosounder data, was used to classify acoustic scatterers (Korneliussen and Ona, 2003). Haralabous and Georgakarakos (1996) demonstrated that morphological metrics, such as rectangularity (length × height/area), can also be useful for identifying some species. Likewise, Korneliussen *et al.* (2009) found that elongation (length/height) is useful for distinguishing between capelin and herring.

LSSS automatically calculated several three-dimensional morphological metrics and other parameters for schools detected with the sonar [e.g. volume, surface, sphericity, $S_v$ distribution, school depth, position, number of nuclei and holes, semi-variance, and distance to surface and bottom (Paramo *et al.*, 2006)]. Some of these were comparable with metrics and parameters derived from the two-dimensional echosounder data.

The corrected maximum and minimum school elongations were defined as

$$E_{\mathrm{max,\ MS70}} = \frac{L_{\mathrm{BC,\ max}}}{H_{\mathrm{BC}}}, \text{ and} \tag{2}$$

$$E_{\mathrm{min,\ MS70}} = \frac{L_{\mathrm{BC,\ min}}}{H_{\mathrm{BC}}}, \tag{3}$$

where $L_{\mathrm{BC,min}}$ and $L_{\mathrm{BC,max}}$ are the horizontal dimensions, and $H_{\mathrm{BC}}$ the vertical dimension of the corrected school-bounding box. A similar metric based on echosounder data is elongation

$$E_{\mathrm{EK60}} = LH^{-1}, \tag{4}$$

where $L$ is the school length and $H$ its height.

## Results

### Net samples

Zooplankton was sampled with nets at locations close to each other for three days, and their combined results (Table 2) are assumed representative of the experimental site. Total lengths ($L_T$) were measured from the anterior edge of the eye to the tip of the telson (Morris *et al.*, 1988). The mean $L_T$ of the three main size groups were: 17.5 mm (*Themisto gaudichaudi* and *Euphausia frigida*); 38 mm (*E. superba*); and 46 mm (*E. superba*), respectively, with standard deviations near 10% of their means. Illustrated in Figure 3 are the position of trawl station 5 (Figure 2) and the depth strata sampled by trawls. The trawl at station 5 was conducted at the same geographic location as the schools in Figures 2 and 3, and supplied the biological sample closest in time to the acoustic data shown here.

### Estimates of zooplankton size

Distributions of standard length 2 ($L_{S2}$), defined as the length from the tip of rostrum to the posterior edge of the sixth abdominal segment, were acoustically estimated for *E. superba* [Figure 3; $L_T \approx 1.24 \times L_{S2} - 0.9$ (mm)]. The $L_{S2}$ (Figure 3e) are compared with the $L_T$ from the catch (Figure 3e and Table 2). The major and minor modes of the length histograms are $L_{S2} = 36$ and 12 mm, which are similar to $L_T = 44$ and 14 mm, respectively (Figure 3e). For the larger mode, the acoustic estimate ($L_{S2} =$ 36 mm) agrees reasonably with the measurements from trawl station 5 ($L_{S2} = 46 \pm 4$ mm) and the mean size of *E. superba*

**Table 2.** Total length ($L_T$) for macrozooplankton sampled north of the Subantarctic island of South Georgia in January 2008.

| Station[a] | UTC time (dd, hh:mm) | Depth (m) | Latitude (S) | Longitude (W) | Species[b] and $L_T$ (mm) |
|---|---|---|---|---|---|
| 1[Å] | 18, 16:40 | 75–105 | 53°56.15′ | 36°24.29′ | *S* = 45.5 ± 4.2 |
| 2[M] | 19, 12:00 | 20 | 53°54.40′ | 36°21.54′ | *S* = 37.9 ± 5.6 |
| 5[M] | 20, 14:30 | 20–26 | 53°41.28′ | 36°21.95′ | *S* = 46.2 ± 4.1 |
| 6[K] | 21, 00:44 | 0–30[c] | 53°43.72′ | 36°18.72′ | *S* = 45.5 ± 4.2; *F* = 19.8 ± 2.0 |
| 8[K] | 21, 17:15 | 150–200 | 53°55.40′ | 36°36.93′ | *S* = 35.6 ± 10 |
| | | 100–150 | | | *T* = 16.8 ± 2.0 |
| | | 50–100 | | | *S* = 46 ± 4; *T* = 17.7 ± 2[d] |

[a]Å, Åkra trawl; M, Single-bag, macroplankton trawl (14 m vertical); K, Multibag, macroplankton trawl.
[b]*S*, *E. superba*; *F*, *E. frigida*; *T*, *T. gaudichaudi*.
[c]Four bags contained *E. superba* of length 45.5 ± 4.2, but one bag contained pure *E. frigida*.
[d]70% of mass in catch was *T. gaudichaudi*, 28.5% was *E. superba*.

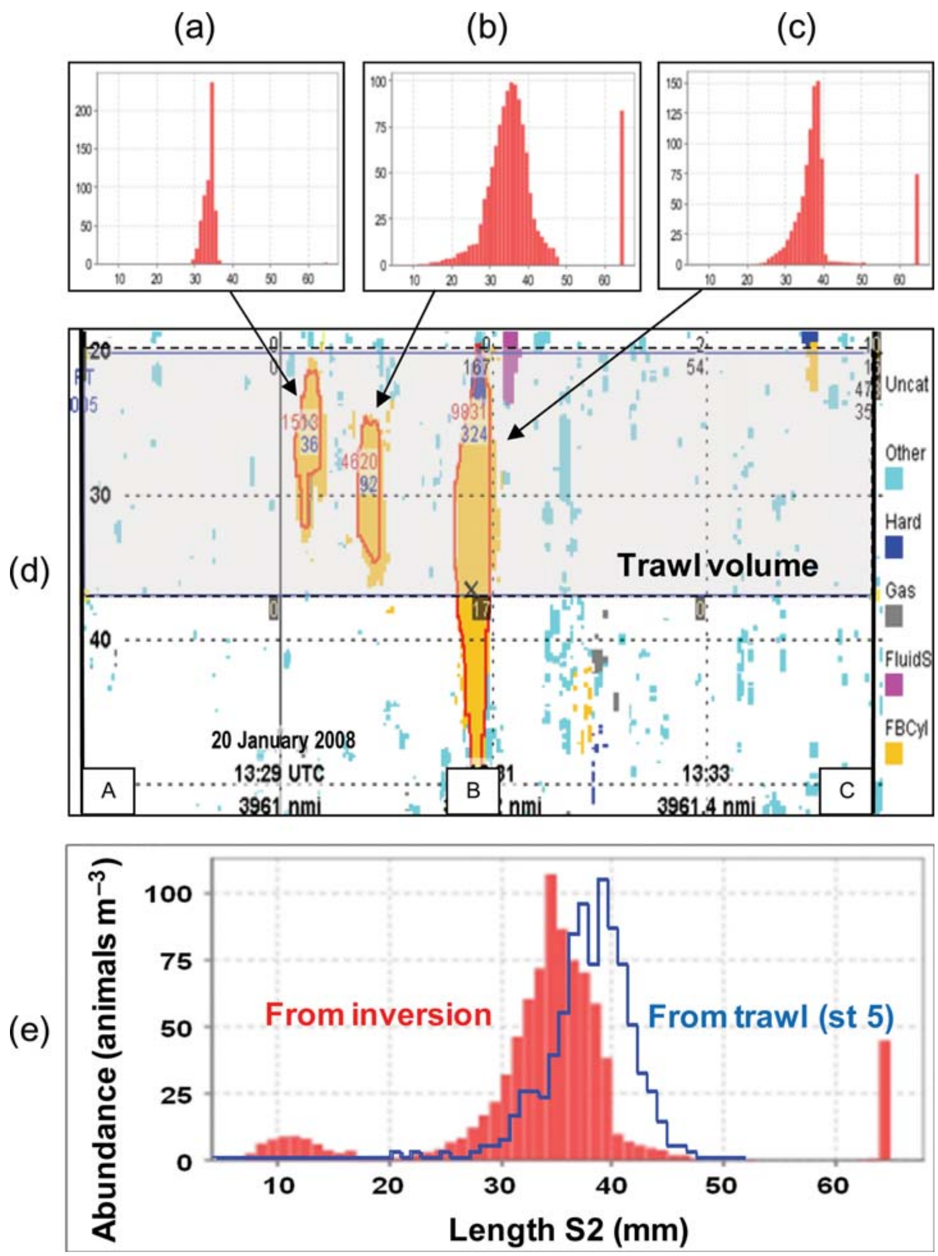


**Figure 3.** Results of the acoustic estimations of zooplankton size composition and net sampling: (a–c) show acoustic estimates of krill length ($L_{S2}$) for three schools, and (d) is a synthetic echogram where orange indicates euphausiids or amphipods. The trawl (grey) traversed 0.325 nautical miles at 2.9 knots. Also indicated are the start of trawling (A), the centre of a box enclosing a krill school (B), and the end of trawling (C). (e) shows acoustic estimates of $L_{S2}$ for krill in the grey area in (d) (red histogram) and result of the net catch (blue curve). The catch contained 99.99% *E. superba* (1000 kg) of $L_{S2}$ = 38.0 ± 3.3 mm ($L_T$ = 46.2 ± 4.1 mm).

($L_T = 43.5$ mm) from all nearby catches (Table 2). The smaller mode (Figure 3e) can be explained by the presence of *T. gaudichaudi* (mean $L_T = 17 \pm 2$ mm; Table 2). The result of $L_{S2} = 65$ mm (Figure 3) is probably an artefact from the acoustic-size-estimation process.

## Estimation of school morphometrics

Elongation metrics were measured over successive sonar pings for 30 entire schools ($E_{max,\ MS70} = 3.0 \pm 1.3$; $E_{min,\ MS70} = 1.7 \pm 0.7$; Figure 2b). Similar values were estimated from the echosounder data for 24 schools sampled along the cruise track ($E_{EK60} = 4.2 \pm 1.2$; Figure 2). These metrics are not directly comparable, because $E_{max,\ MS70}$ and $E_{min,\ MS70}$ were corrected values based on multiple measures of the entire school, and $E_{EK60}$ was uncorrected and based on interpolation of vertical dimensions from many pings. However, multiple-frequency estimates of $E_{EK60}$ allowed precise estimates of mean $E_{EK60}$. Although boundary boxes on the sonar data also improved the measurement precision, a random slice through the school volume was generally not as deep or wide as the box. Therefore, $E_{EK60}$ was generally larger than $E_{min,\ MS70}$, but smaller than $E_{max,\ MS70}$.

Only four of the schools observed with the sonar were also observed with the echosounders; two of these have been mapped (Figure 2). It appears that the ship crossed the shortest width dimension of all four schools; therefore, $E_{EK60}$ should be comparable with $E_{min,\ MS70}$. The schools had the following elongation values ($E_{max,\ MS70}$, $E_{min,\ MS70}$, and $E_{EK60}$): 5.4, 3.9, and 3.5 (Figure 2c); 5.2, 2.7, and 2.2; 5.2, 2.9, and 3.3; and 6.8, 2.3, and 4.4. For these four schools at least, the $E_{min,\ MS70}$ values did not differ from their respective $E_{EK60}$ values.

## Discussion

School morphology can be used for species ID. Korneliussen *et al.* (2009) used elongation $E_{EK60}$ to distinguish between capelin ($E_{EK60} = 4.0 \pm 1.9$) and herring ($E_{EK60} = 6.5 \pm 3.0$) of similar size measured in Norwegian waters. The $E_{EK60}$ distinguished capelin and herring, although it was not known whether the school was crossed in its longest or shortest dimension, or in any another direction. Although only a few schools measured here were located and orientated such that their shortest dimensions could be sampled (i.e. $E_{EK60}$ and $E_{min,\ MS70}$ are comparable), the results support the hypothesis that school metrics derived from the sonar data could be used for acoustic classification of taxa or species. Because the cross sections $E_{max,\ MS70}$ and $E_{min,\ MS70}$ were estimated from three-dimensional school images, they probably provide more accurate and precise morphological measures than $E_{EK60}$, and should therefore improve species IDs.

The $E_{EK60}$ for Antarctic krill ($4.2 \pm 1.2$) did not differ much from those measured for capelin ($4.0 \pm 1.9$) in Norwegian waters. However, $E_{max,\ MS70}$ and $E_{min,\ MS70}$ remain to be measured for capelin.

The sonar can measure an entire school in three-dimensions with a single ping (Figure 4), and such measurements can be repeated rapidly. These data can be animated and rotated, allowing a four-dimensional visualization of the school's dynamic position and shape. Some of the possible school metrics are:

$$\text{sphericity:} \quad \psi = \pi^{1/3}(6V)^{2/3}S^{-1}, \tag{5}$$

$$\text{corrected school volume:} \quad V_C = V \cdot V_{BC}V_{BU}^{-1}, \tag{6}$$

$$\text{corrected surface:} \quad S_C = S \cdot S_{BC}S_{BU}^{-1}, \text{ and} \tag{7}$$

$$\text{mean volume-backscattering strength:} \quad S_v(\text{dB re } 1 \text{ m}^{-1}), \tag{8}$$

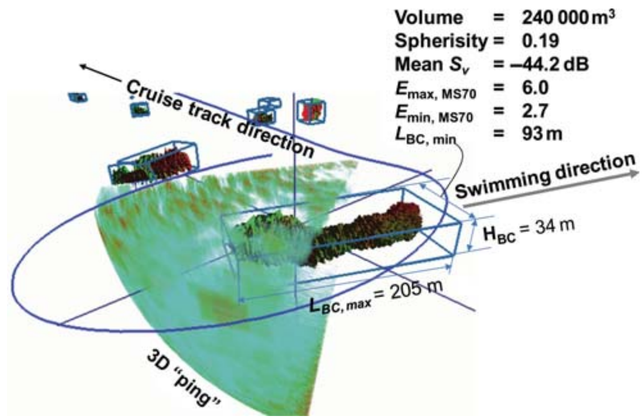


**Figure 4.** A three-dimensional visualization of schools, the cruise track (blue curve), and one MS70 ping partly covering a single school. The schools are detected with several pings. The school is moving in direction from green to red colour (arrow). The bounding boxes are the outer extent of the three-dimensional schools. The quantitative measures are only for the marked school.

where $V = \sum_i V_i$ is the sum of elementary volumes $V_i$ over all samples $i$, $V_{BU}$ and $S_{BU}$ are, respectively, the volume and surface of the uncorrected bounding box, and $V_{BC}$ and $S_{BC}$ are, respectively, the volume and surface of the corrected school bounding box (Figure 4). Validating the MS70 measurements is difficult, because relatively few comparable measurements are available from echosounders sampling the same schools.

Echosounders are used to measure the distribution and abundance of zooplankton without frequent and time-consuming biological sampling. Biological sampling will remain indispensable to verify species and their size composition, but the MS70 now allows acoustic observations of zooplankton to extend beyond the volume sampled with the echosounders and nets during abundance-estimation surveys.

Currently, acoustic estimates of zooplankton size composition are more uncertain than similar estimates for pelagic fish. However, LSSS is sufficiently fast to facilitate continuous use and rapid development in this area of research.

The requirement that data have to be assimilated from several instruments is partly overcome by the automatic processing of the acoustic data before any manual interpretation, and partly by efficient analysis tools. The goal is to allow experienced scientists to process all the acoustic data collected during 24 h optimally within 2 h. To expedite the acoustic-data analyses, LSSS suggests candidate schools and zooplankton-size classes. The two-dimensional, three-dimensional, and four-dimensional acoustic data can then be post-processed with the same user interface. Examples of the interface are illustrated in Figures 2–4.

## Conclusion

With the advent of ecosystem-based fishery management, it has become increasingly necessary to make acoustic observations of the entire water column (Figure 1) and to process these data from multiple acoustic systems efficiently during surveys. The new MS70 sonar allows measurements to be made of schools that are close to the surface and therefore inaccessible to echosounders. Provided *TS* is accurately estimated vs. incidence angle, animal abundances can be estimated from sonar estimates of $V$ and $S_v$.

The identification of taxa and species with multifrequency-echosounder data are now done routinely. School morphometrics, available from the three-dimensional and four-dimensional data from the MS70, are also useful in this context. Therefore, sonar data, occasionally supported by multifrequency-echosounder and net-sampled data, can be used for species IDs. The three-dimensional morphological data are more reliable than the two-dimensional data collected with an echosounder and could therefore improve these IDs. Future combinations of three-dimensional morphometrics and broad-bandwidth pings of sonars could lead to further advances in this area.

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