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The relative frequency response, as derived from individually separated targets on cod, saithe and Norway pout

by

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Abstract

The relative frequency response is an important acoustic feature used to characterise acoustic targets. This response has been defined as the s_v, volume backscattering coefficient, for a specific frequency relative to that of a reference frequency (38 kHz). The acoustic data commonly used in these calculations are derived from integrated measurements in a region containing multiple targets. In this study the relative frequency responses at 18, 38, 70, 120, and 200 kHz have additionally been measured using filtered target strength data on all frequencies. The spatial comparability of the s_v-data is thus avoided, while the single-target detection becomes a new challenge. Target strength was extracted from *in situ* measurements, using calibrated and digitised data from a Simrad EK60 with split-beam transducers transmitting simultaneously at all five frequencies. Selected series with nearly pure catches of Atlantic cod (*Gadus Morhua L.*), saithe (*Pollachius virens L.*) and Norway pout (*Trisopterus esmarkii L.*) were analysed. The frequency response derived by the new method is compared with standard integration method.

Keywords: acoustic, relative frequency response, multi-frequency, target strength.

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Introduction

Analysis of echo sounder signals in the frequency domain has shown that some fish species may have a quite specific reflected spectrum (Midttun & Nakken, 1972; Holliday, 1972; Foote *et al.*, 1992; 1993; Horne, 2000; Korneliussen & Ona, 2002; 2003). For some fish and especially for zooplankton, the frequency region between 18 and 200 kHz have been available and successfully used for some years now. However, for recordings of large, single targets, the methods developed for multi-frequency pixel-based analysis of the frequency response has not been optimal for identification. This analysis has basically directly compared the received calibrated amplitude, s_v, at each frequency, assumed detected within the same (identical) pulse volume. (See Korneliussen *et al.,* 2004 for recommendations on data collection). For one single target, however, the volume backscattering coefficient recorded for single detections and tracks are not corrected for target position. A second problem is that the target is not observed from exactly the same point, (transducer position and transducer directivity) and thus compensated differently on the individual frequencies in uncompensated mode. A third problem is related to the backscattering by the fish itself, and its frequency dependent directivity pattern. The recorded frequency response, therefore is severely dependant on the tilt angle of the observed individual fish, and may vary significantly between fishes of the same size and species. A stable frequency response for single targets is thus only achieved by the echo integration method when the standard criteria for echo integration (and the linearity principle, Foote, 1992) is satisfied, namely large enough target numbers for assuming random target distribution within the sampling volume.
Detailed pixel-by-pixel analysis of non-smoothed multi-frequency echo sounder recordings may be used to create new synthetic echograms of the frequency response, but may, as argued, not represent the true frequency response for single targets. As these new echograms are used for target identification, single targets may therefore be misclassified if the classification criteria are set too narrow.

In this paper, we try to extend the method to single targets, by directly comparing the detected target strength of the individual targets and tracks, as sensed by the five split beam detectors of the echo sounders. With full calibration and mapping of the beam position and directivity, as well with the motion of the vessel, we aim to remove the first two problems. The remaining variance in the recorded frequency response on single targets is then the variability caused by the directivity pattern of the fish itself and its tilt angle during detection. A comparison to the averaged frequency response will be made.

Material & Methods

Echo sounder recordings using five Simrad EK60 split beam echo sounders were made from R/V “G. O. Sars” during the Lofoten 2004 survey on the spawning grounds of the North East Arctic Cod. The survey covered the shelf between 500 m to about 50 metres depth on the outside and inside of the Lofoten islands, from 67ºN to 70ºN, lasting from March 17 to April 5, 2004 (Figure 1). The sea temperature in the vicinity of the sites for TS measurements was nearly constant, 6.8 –

7.1°C from about 40 – 300 meters depth. The echo sounders were calibrated by standard sphere calibration methods (Foote *et al.,* 1987), both with respect to centre sensitivity, pulse duration and split beam target compensation as described in detail in the Simrad EK60 manual. The calibration spheres used were CU64 (18 kHz), CU60 (38 kHz) and the WC38.1 (70, 120 and 200 kHz). All transducers are mounted in one of the instrument keels of the vessel in a maximum packing arrangement, and have all a nominal full half-power beam widths of 7°, except for the 18 kHz, which is wider, 11°. The echo sounders were operated in parallel at maximum pulse repetition frequency (PRF), transmitting soon after the bottom echo was safely received (Table 1). For the sake of comparability, the transmitted pulse duration was identical on all frequencies, 1.024 ms, only occasionally changed on one sounder for improved vertical resolution. In order to avoid unwanted acoustic non-linear effects (Tichy *et al.*, 2003), the transmit power on each frequency was set according to recommendations by the Institute of Marine Research and Simrad. All raw data from the echo sounders were stored in addition to the data transmitted to the post processing system used for analysing the survey data, the Bergen Echo Integrator, BEI (Foote *et al*., 1992). Vessel movement, as heave, roll, pitch and yaw was logged from the Seatex MRU 5 to the bottom topography system Simrad EM 1002 at 10 Hz, and to the ping data file in the ER60 echo sounder. Environmental and oceanographic information was obtained from CTD observations (Sea-Bird SBE9).

Trawling on this particular survey was conducted as usual for these surveys, partly on fixed locations, but mostly on registrations for identification of the targets and for biological sampling. The trawl used were the Campelen 1800 bottom survey trawl and the Åkratrawl, a medium sized midwater trawl (see Fernø & Olsen, 1994). Standard biological parameters were measured on all catch samples, individual total length, weight, gonad and liver index, age and stomach content. The survey report (Mehl, 2004) is available at www.imr.no

The frequency response of selected parts of the echograms was continuously monitored in the BEI system and time for the clean registrations and trawl stations were tagged for further analysis. The detailed analysis of the recorded raw ER60 data were done in special modules developed in MatLab, both for reconstructing new echograms, echo integration, target strength analysis, target tracking and vessel motion removal. Target tracking algorithms recently developed by Handegard (Handegard, 2004) were used, and new displays of single and multiple target frequency response were developed here.

Definitions:
Relative frequency response, individual targets:

$$r_i(f) = \frac{\sigma_i(f)}{\sigma_i(38)} \tag{1}$$

Average relative frequency response, multiple targets:

$$< r(f) >= \frac{s_v(f)}{s_v(38)} \tag{2}$$

All averaging is performed in the linear domain, although the results may be presented in logarithmic form.

Results and Discussion

Echogram examples from the three selected species which could be found in clean concentrations, and also largely as resolved single targets are shown in Figure 2, a), b) and c). First, all three species with a physoclist swimbladder showed a clear-cut averaged frequency response, with a sharp fall from 38 kHz towards higher frequencies. The falloff seemed to be very size dependant, as the Norway pout is significantly smaller than the two larger fishes, saithe and cod. The mean size distribution of the three species from the selected area is shown in Figure 3.

The target strength distribution at five frequencies for cod, saithe and Norway pout is shown in Figure 4. Note the gradually change in the modal character of the TS distribution with frequency and size. For the large cod at high frequencies, the TS distribution becomes nearly Raleigh distributed in the logarithmic domain. A target-tracking algorithm was used to track single target of the three species in question. Exemplified results from this procedure are shown in Figure 5. Mean target strengths of 10 single target tracks at five frequencies, picked at random, are given as well as the mean target strength for all tracks. Mean target strength for all targets of the three species is shown in Figure 6. By using equation (2) the relative frequency response for single targets are given for cod in Figure 7. Mean target strengths at the different frequencies are summarised in Table 2. It is clear that the response based upon individual, beam compensated detections resemble the averaged response, but exhibits a smaller individual variability than do the direct, uncompensated response. One of the echograms in the ER60 may display only beam compensated, accepted single targets; Sp&TS- echogram, and the real variation, track by track may therefore be studied visually. The sharper directivity in the tracks of saithe may in this manner be used for identification. A new display for enhancing the frequency dependant within variability is needed for such analysis.

For direct comparability, it is also important not to use an observation range that exceeds the limits of observation for one or more of the frequencies. This range is dependant on several parameters including the echo sounder parameters and the noise. A qualitative investigation of the observation range, based on the number of observation at different ranges and frequencies, indicates that the deeper recordings at 200 kHz of Norway pout might be stretched a bit far, and in the further analysis, a more quantitative approach will be made. Now, only recordings within three degrees from the acoustical axis were used in this analysis, and a lower TS limit of –50 [dB re 1m^2] was set on all sounders. A better representation of the pout data would have been made if applying a lower TS threshold.

Several conclusions may however be made from this preliminary analysis of the data: 1: the mean target strength of all three species is clearly decreasing with increasing frequency. 2: Differences in fish directivity and size seems to determine the falloff rate in r(f) and r_i(f). 3: The information in r(f) combined with target strength could readily be used to identify the three species in this particular survey. 4: Applying modelling information on fish directivity and combined target tracking may further be tried for extracting the tilt angle distribution of the targets by inversion methods.

Acknowledgement

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FIGURES

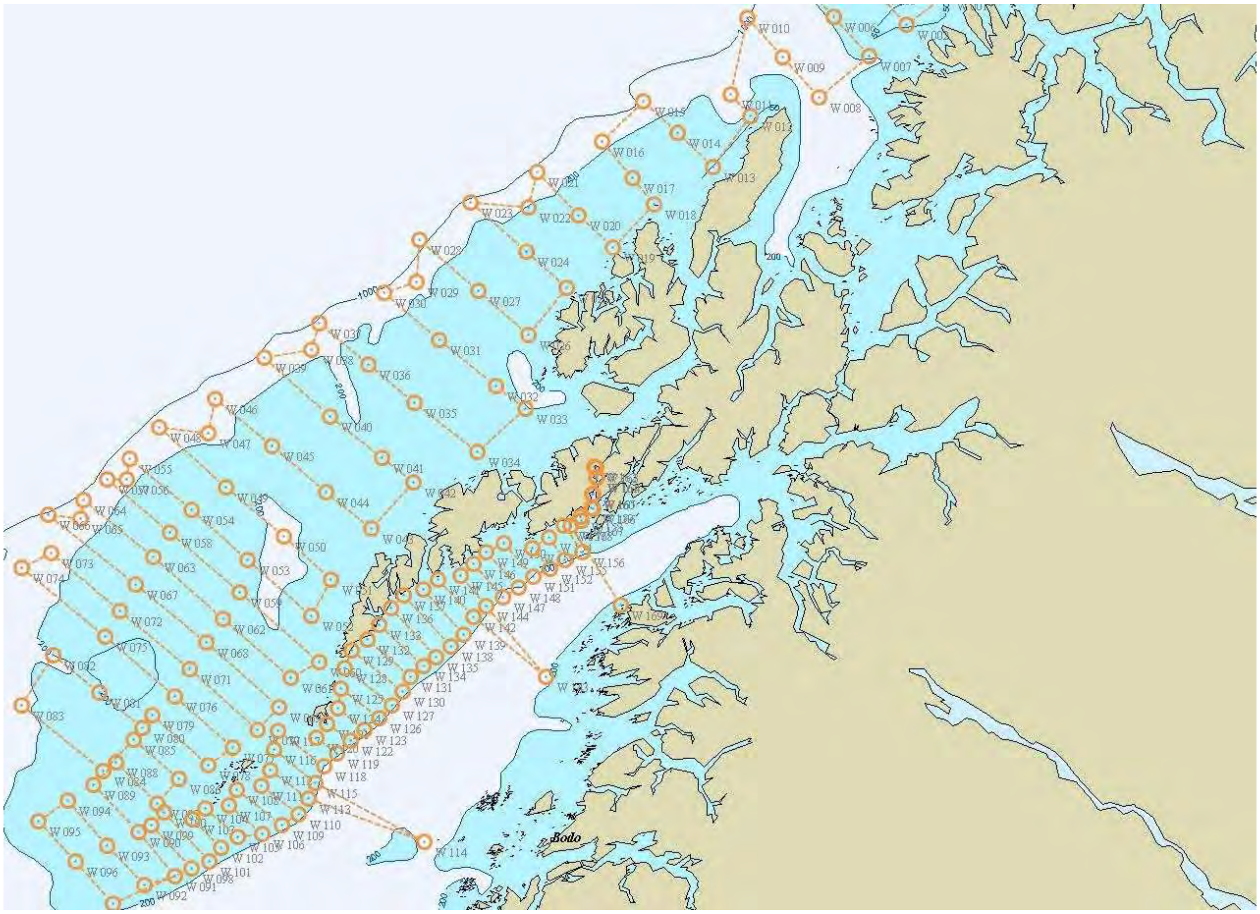

Figure 1. Survey lines for the Lofoten 2004 cod survey.

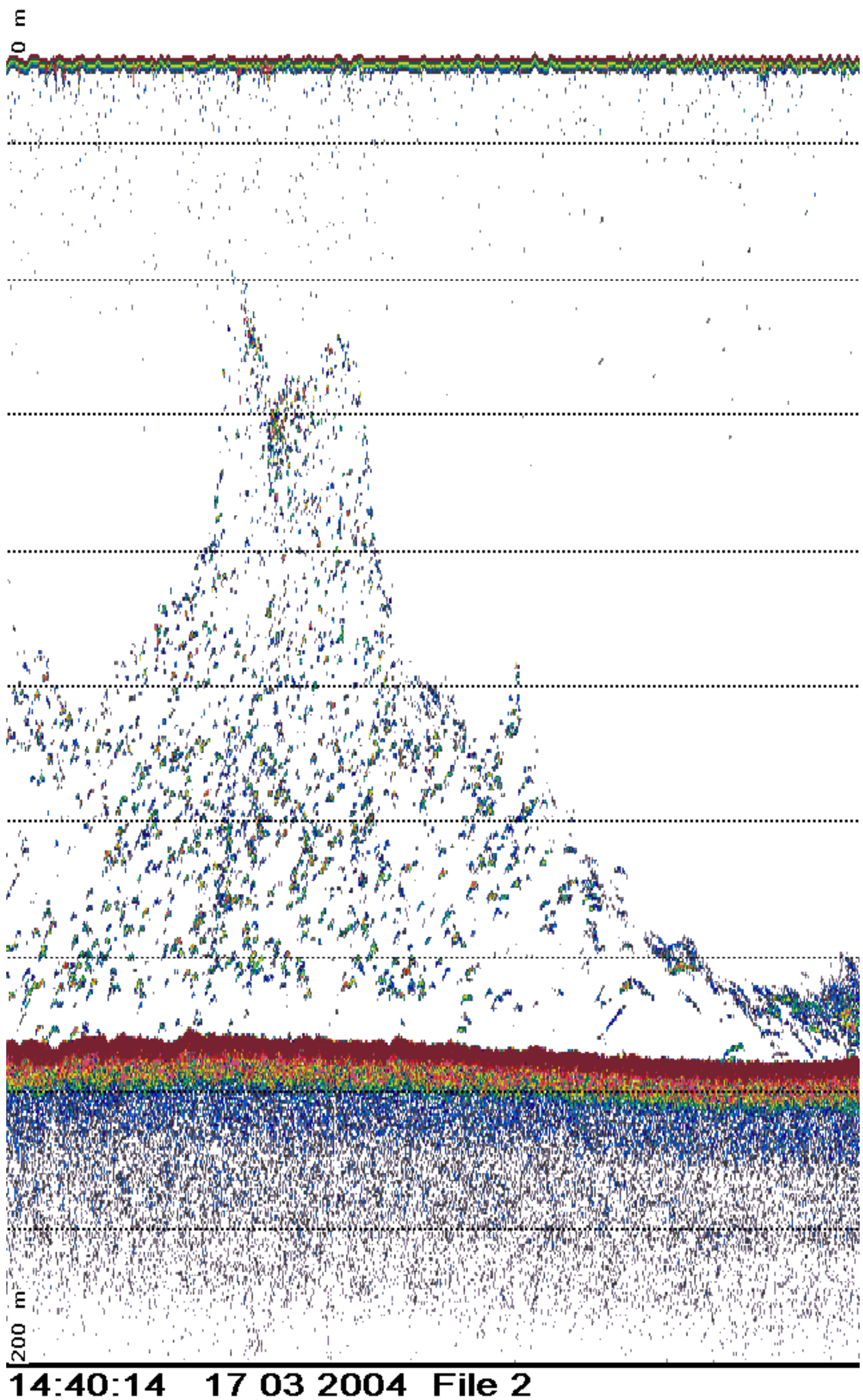

Figure 2 a). Example of typical saithe registration (shoal dispersing) used for extracting the frequency response of single targets at five frequencies. 38 kHz is shown here.

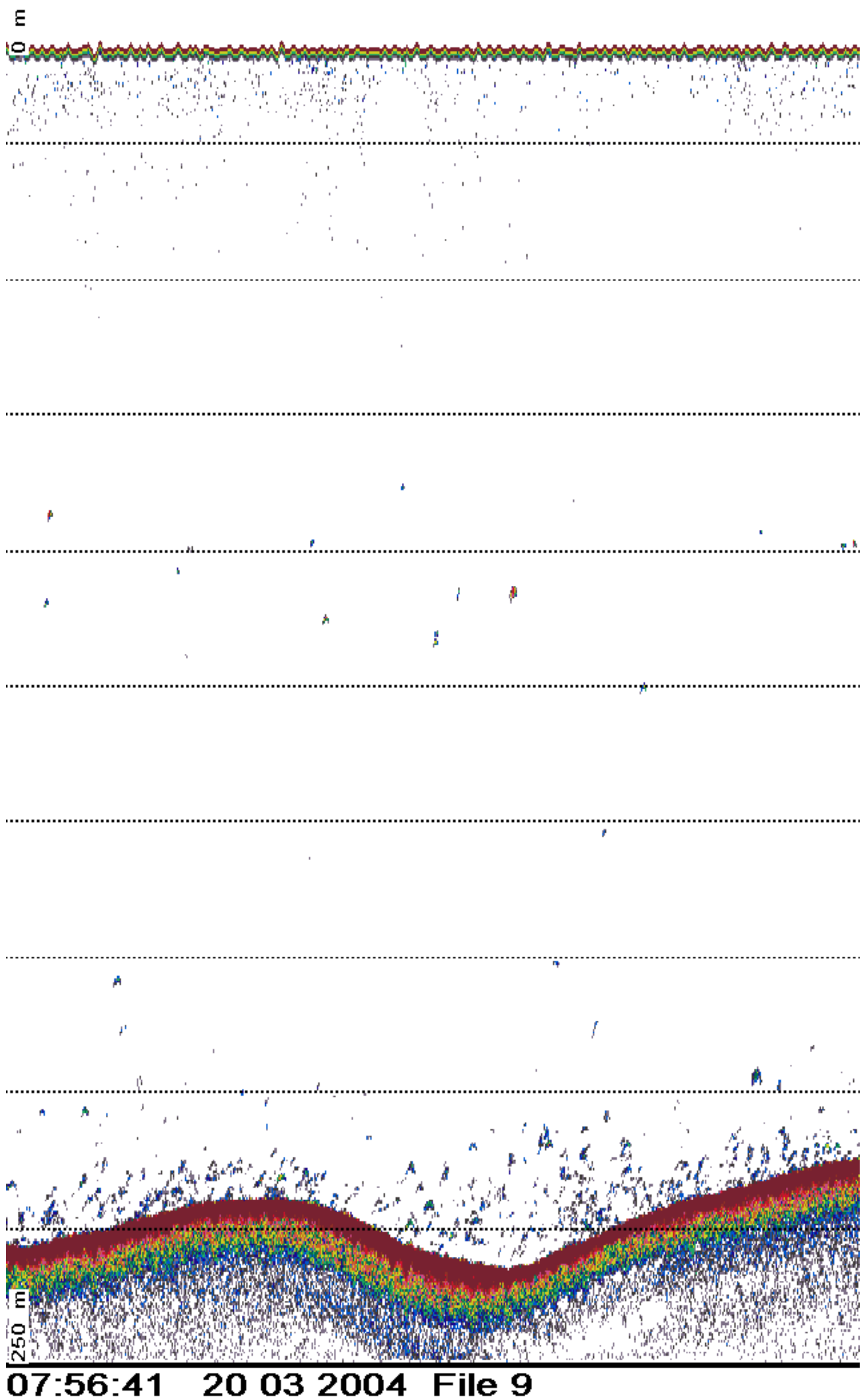

Figure 2 b). Example of registration, (0 -250 m) of clean Norway pout (lower 25 meters) for extracting the frequency response of single targets at five frequencies. 38 kHz is shown here.

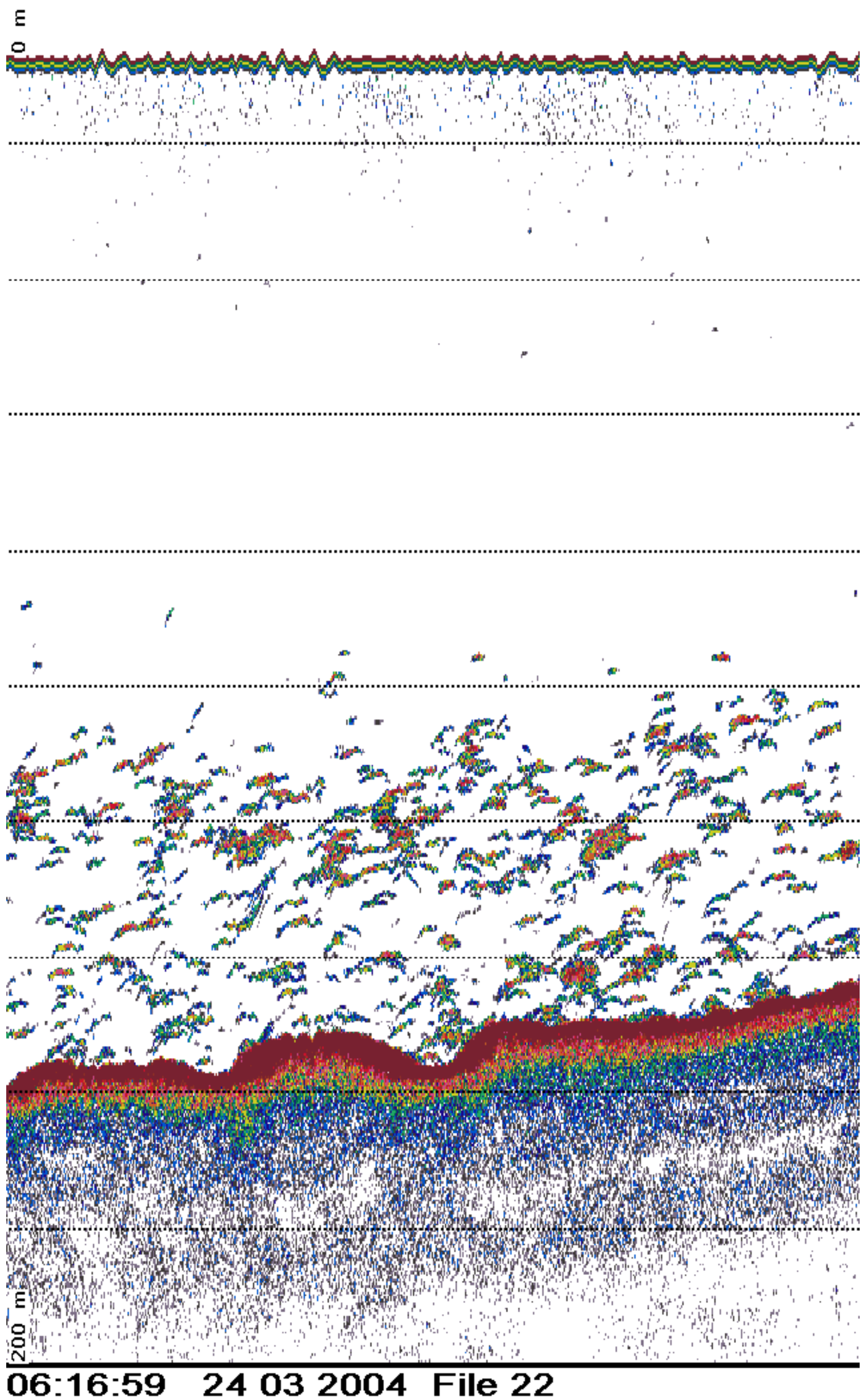

Figure 2 c). Example of good registration (0 – 200 m) of clean cod used for extracting the frequency response of single targets at five frequencies. 38 kHz is shown here.

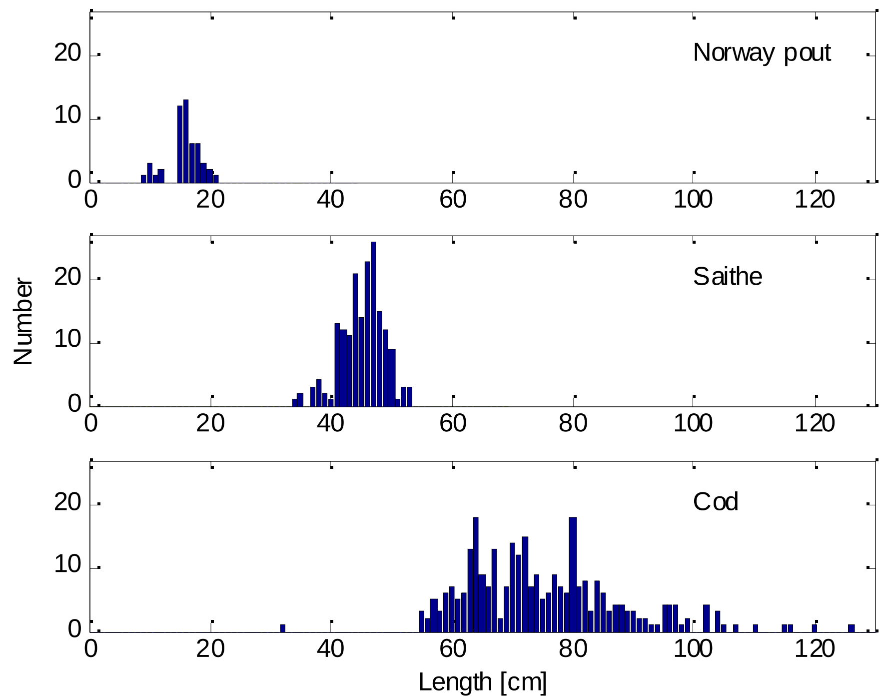

Figure 3. Length distributions of the three species from the area in which the target strength recordings were made. A total number of 455 fish were measured, 50 specimens of Norway pout, 176 of saithe, and 299 cod.

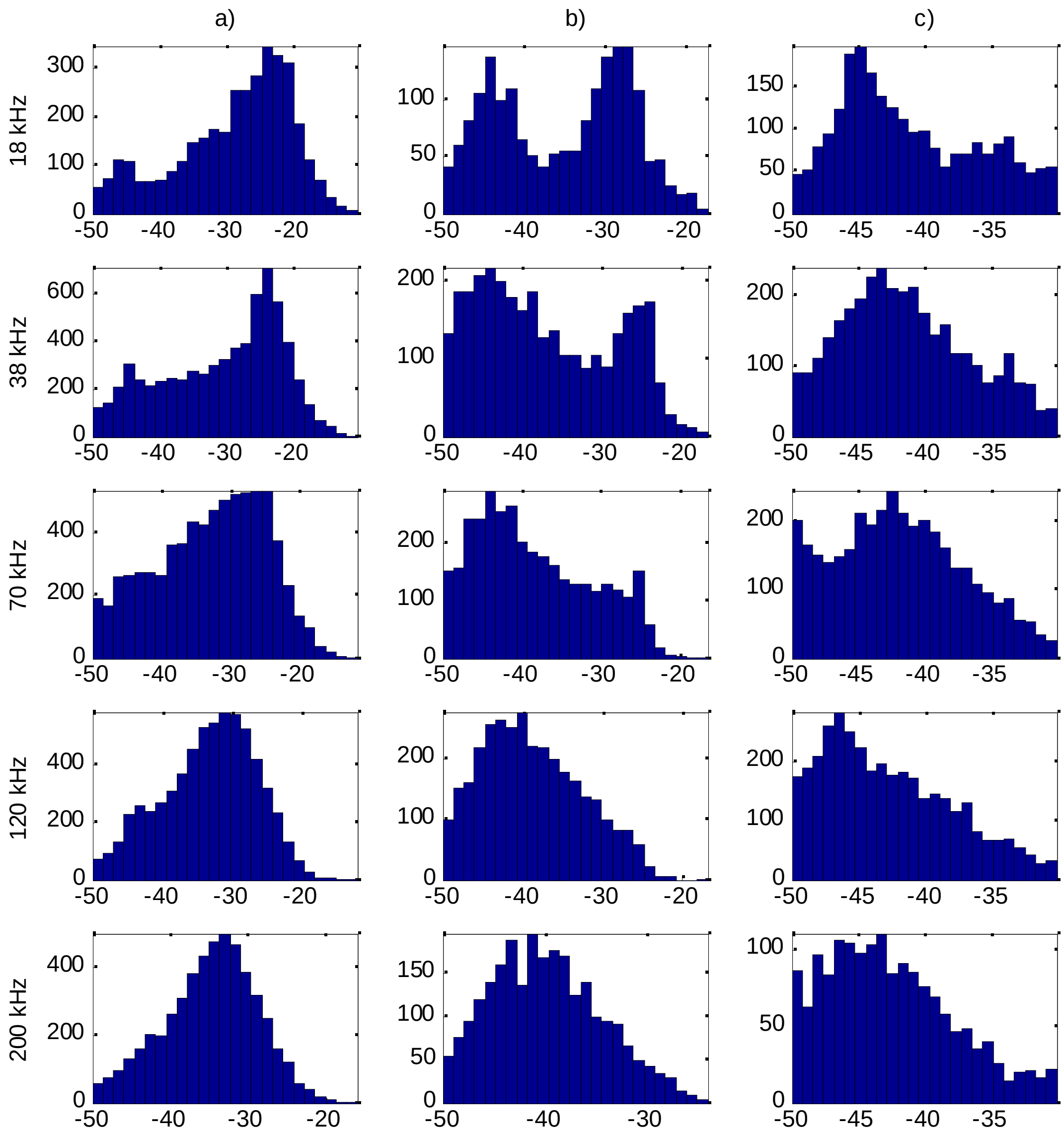

Figure 4. Target strength distributions of a) cod, b) saithe, and c) Norway pout.

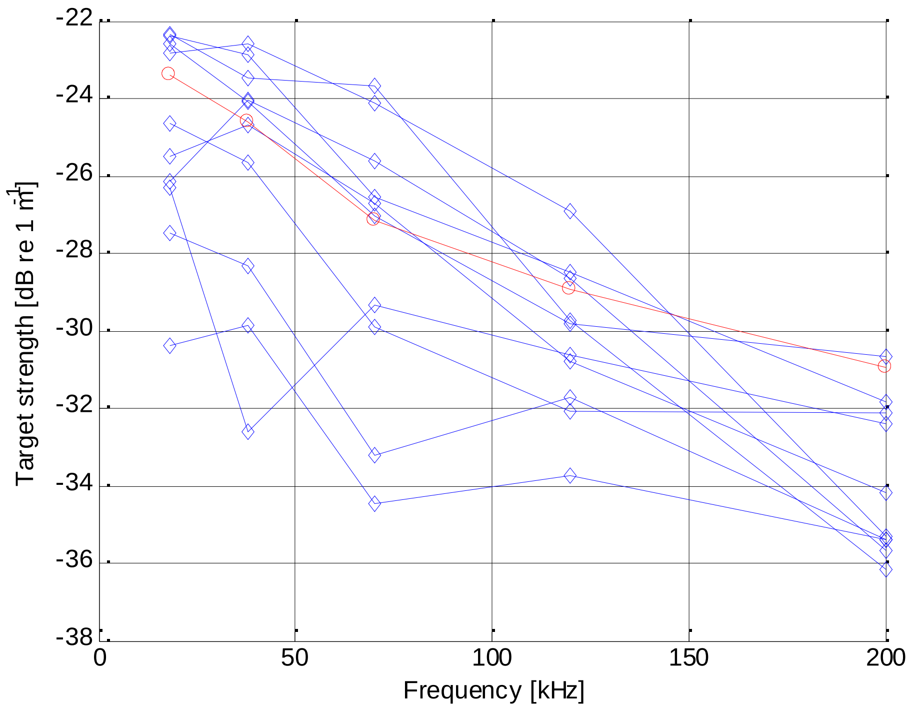

Figure 5. Mean target strengths for 10 single tracks of cod chosen at random (blue full line) and the mean target strength for the whole aggregation of cod (red broken line).

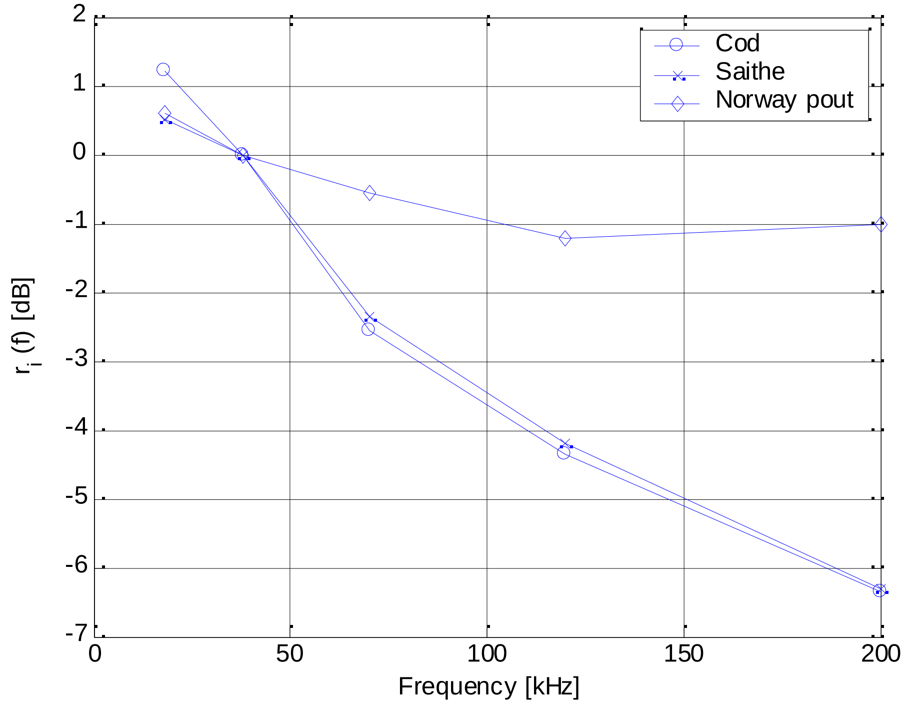

Figure 6. Mean target strengths vs. frequency for the three species.

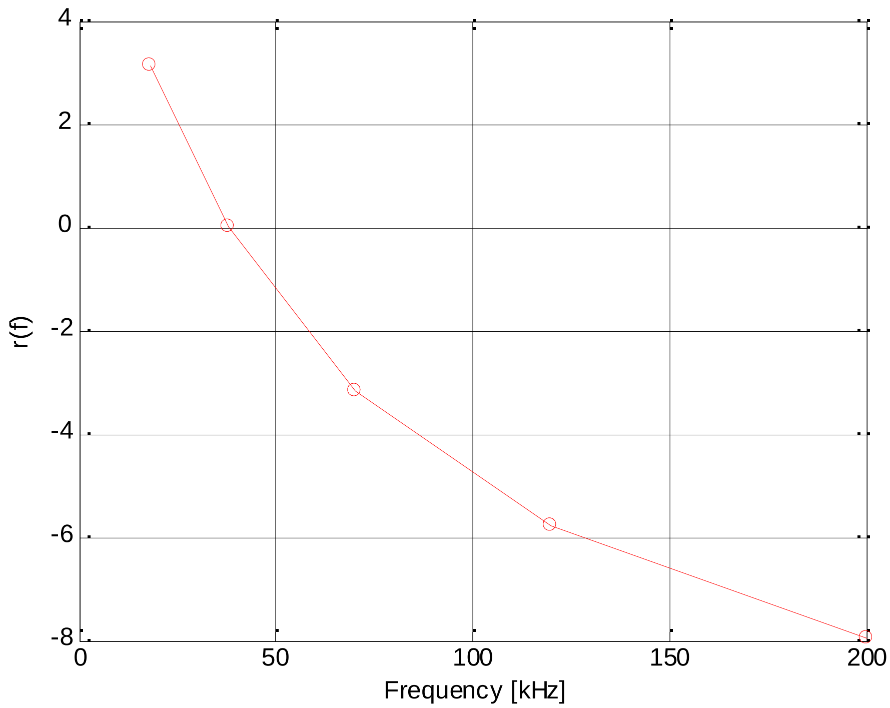

Figure 7. Frequency response for cod based on s_v (Equation 2).

TABLES

Table 1. Operating parameters of the five transducers on the R/V G. O. Sars.

Frequency [kHz]	Power [W]	Receiver bandwidth [kHz]	Absorption coefficient [dB km^{-1}]
18	2000	1.57	3.17
38	2000	2.43	10.39
70	1000	2.86	20.33
120	250	3.03	30.00
200	120	3.09	43.11

Table 2. Mean target strength <TS> for different measurement series.

Frequency [kHz]	Cod <TS> [dB re 1m^2]	Saithe <TS> [dB re 1m^2]	Norway pout <TS> [dB re 1m^2]
18	-23.6	-30.1	-38.0
38	-25.0	-30.5	-38.6
70	-27.5	-32.7	-39.2
120	-29.3	-34.6	-39.8
200	-31.4	-36.8	-39.6