On acoustic multi-frequency species identification and separation of Atlantic mackerel, Norwegian spring spawn herring and Norway pout.

by

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ABSTRACT

The accuracy of the multi-frequency species identification and separation algorithms may be significantly improved when the detailed acoustic scattering characteristics of the fish are known, including its expected variability and uncertainty. The modeling approach is effective for interpreting measured data collected for different fish species and may give a better understanding of the acoustic scattering characteristics. The paper is motivated by development of algorithms of multi-frequency species identification and separation of three economically valuable North European fish species: Atlantic mackerel, Norwegian spring spawn herring and Norway pout. The backscattering by these fish is studied using an advanced modeling approach, and the results of the analysis are compared with selected multi-frequency recordings. This allows for an explanation of the main backscattering mechanisms over the selected frequency range and often a better understanding of the dominating acoustic scattering parameters. The impact of fish orientation behavior, pressure (for herring) and the morphological state of the fish is also discussed. Typical backscattering frequency responses for herring, mackerel and Norway pout are explained theoretically. The obtained results may be a base for improving the automatic identification algorithms now introduced in scientific echo sounder post-processing systems.

INTRODUCTION

The improvement of multi-frequency techniques of fish species identification remains a long-term objective of fisheries acoustics (Horne, 2000). In order to develop classification procedures for valuable fish species like Atlantic Mackerel, Norwegian Spring Spawn Herring and Norway Pout, selected series of the multi-frequency recordings have been made during regular surveys. These have demonstrated that for mackerel and herring the echo levels at different frequencies, the frequency response, are quite species-specific. The pure frequency response for pout has only occasionally been measured, as most of the registrations of pout schools and layers were slightly mixed with other fish species.

Korneliussen and Ona, (2002, 2003), found a quite specific frequency response for mackerel; a rather flat response at 18, 38 and 120 kHz and then sharply increased backscatter at 200 kHz. Unpublished measurements made in net pens before 2002 and at sea confirm the frequency-independent backscatter at 18, 38 and 70 kHz, and the stronger backscatter at 200 kHz. In some measurement series, however, backscatter at 120 kHz, was similar to that at 38 kHz, and in other up to twice as great.

Numerous surveys with multi-frequency recordings on herring has definitely shown other specific pattern; demonstrating a weakly decreasing response with increasing frequency. Measurements also demonstrate a depth-dependence of the frequency response for herring (Ona and Korneliussen, 2000, Korneliussen et al., 2002). Ona and Korneliussen (2000) indicate that this effect can be partially due to differences in behaviour of herring at various depth, expressed as difference in tilt-angle distributions (Huse and Ona, 1996), and the depth dependent target strength (Ona, 2003).

For understanding the observed spectra for mackerel, acoustic modelling has been conducted (Gorska et al. 2004 a, b). These provided a better understanding of the physical, anatomical and behavioural impacts on backscattered sound and of the contribution of various parts of fish in the total backscattering. Some theoretical work on the pressure dependent scattering by herring was also conducted by Gorska and Ona (2003 a, b). These results are useful in the interpretation of the measured frequency response of herring.

In the present paper we shortly summarise the results of the previous modelling activity for mackerel together with a set of new model simulations for mackerel, herring and pout. The frequency response, and its stability are the main focus. It is also demonstrated that the modelling activity needs more detailed morphological data than the ones available for this study.

MATERIALS AND METHODS

The modelling approach (analytical solutions and approximations) was discussed in details in (Gorska et al. 2004 a, b) for mackerel and in (Gorska and Ona 2003 a, b) for herring. The combined approach was used to describe the backscattering by mackerel. Accounting for that mackerel flesh has material properties that are similar, within a few percent, to those of the surrounding water, Distorted Wave Born Approximation - based Deformed Cylinder Model (DWBA - DCM) has been employed to study sound backscattering by mackerel flesh. Actual morphology of mackerel (body shape) has been considered. The Modal-Based - Deformed Cylinder Model (MB – DCM) was used to study backscattering by the backbone, what is justified by significant backbone elongation. The backbone was modelled in two different ways: as an elastic solid straight cylinder of uniform composition profile and as an elastic solid uniformly bent cylinder of constant radius of curvature of its axis, constant cross-section radius and constant composition profile.

For the backscattering by herring (for both – body and swimbladder) the solution consist of two parts - the part responsible for the backscattering in normal dorsal direction and the directivity pattern. The first part is obtained using MB-DCM and approximating swimbladder and body as elongated prolate spheroids. For the directivity pattern the simple solution for a straight cylinder was employed. The directivity formulas for both swimbladder and body were successfully tested against measurements and DWBA – DCM calculations respectively. Both parts of the solution describing the backscattering by swimbladder took into account the swimbladder compression with depth.

To describe backscattering by pout the approach presented in (Gorska and Ona 2003 a, b) was employed. Accounting for that pout has a closed (physoclistous) swimbladder, for

which the backscattering by swimbladder is dominant, the depth dependence due to swimbladder compression was extracted from the backscattering solution.

All available data on fish morphology like allometric relationships for different body parts and sound speed and density contrasts within their tissues were used in the calculations (see the details in (Gorska and Ona 2003 a, b) for herring and (Gorska et al. 2004 a, b) for mackerel). The incompleteness of the data should be remarked, that complicates the study.

RESULTS AND DISCUSSION.

FREQUENCY RESPONSE AND BACKSCATTERING MECHANISMS.

Understanding the backscattering mechanisms is very important for explaining of the measured frequency responses. We consider three fish species with quite different back scattering mechanisms: mackerel, fish without swimbladder, herring, a fish with open, compressible swimbladder, and pout, a relatively small fish with closed swimbladder. Only for pout it is well known that the backscattering by the swimbladder is dominant. For mackerel and herring the situation seems more difficult and we further presents some results, demonstrating the role of the different parts of the fish to the total backscattering from these.

Backscattering by mackerel.

Gorska et al. (2004b) showed that the backscattering by mackerel can not be explained by the backscattering by only the fish flesh. The analysis of backscattering by mackerel flesh showed that the mean backscattering cross-sections, which define the frequency response, are nearly the same at 120 and 200 kHz over the entire range of mackerel parameters. However, this disagrees with the measured frequency response, which sharply increases between 120 and 200 kHz. This indicated that other backscattering mechanisms were equally important, like backscattering from the backbone and head.

When considering the backscattering by both flesh and backbone, averaging the backscattering solutions for individual fish (Gorska et al., 2004a), over mackerel length and orientation distributions, the results shown in Fig. 1, were obtained. A comparison of measured (blue curves) and computed (red curves) frequency responses is offered in the figure. The computations were performed for mean total length of mackerel 42 cm and density and sound speed contrasts in the flesh of 1.03. A standard deviation of 10% was used to represent the length distribution, and the mackerel orientation distribution was modelled thorough a normal distribution (N: 0,3), indicating a mean tilt angle of 0 degrees and a spread (SD) of 3 degrees. In our analysis a shift angle between the main axis of the mackerel body and the backbone of 3 degrees was used. For backbones the calculations were done for six measured backbones of density contrast 1.1 and sound speed contrast of compressional wave 1.3. For each backbone the curves were generated for sound speed contrast of shear waves varies over the range from 0.1 to 0.9. Only the curves which fitted the measurements were selected and presented in Fig. 1.

The comparison verified that including the backbone might allow for an explanation the observed increase in the frequency response at higher frequencies. More detailed analysis, demonstrated that for frequencies lower than 70 kHz, backscattering by the flesh is dominant, while for frequencies higher than 120 kHz, backscattering by backbone is very important.
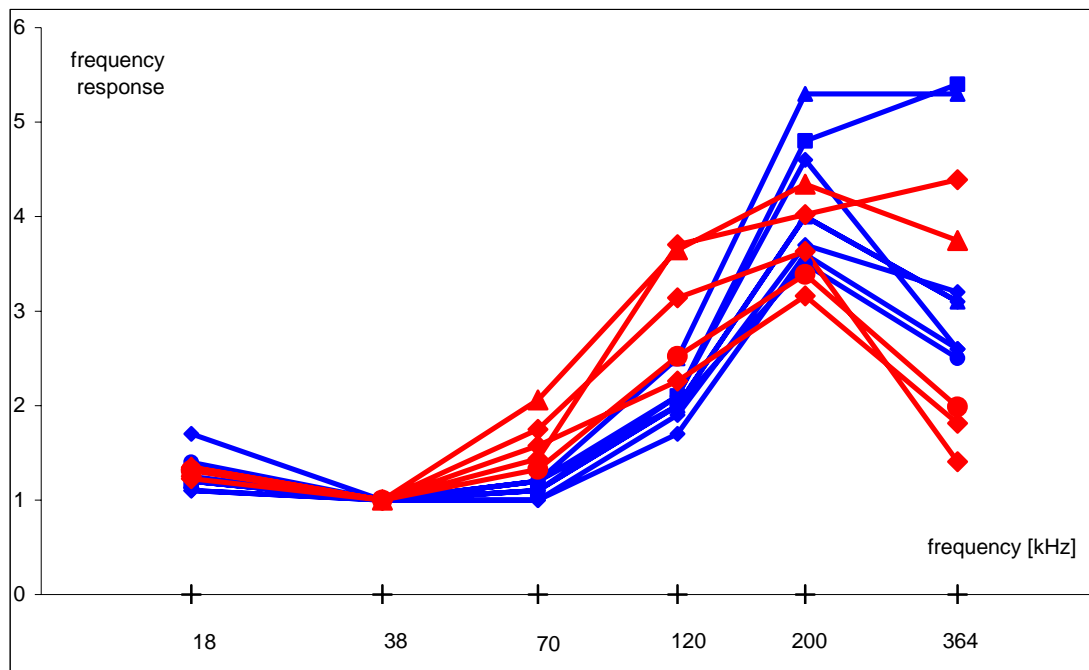
Fig. 1.

Comparison of measured and calculated frequency responses for mackerel.

The calculations demonstrated which parameters may dominate the frequency response. The results are presented in Table 1, in which in the first column the controlling parameters, in regard to which the sensitivity of the frequency response was studied, are given. Their variability is indicated. In the next columns the variability (in dB) of the respective frequency responses (see first row) is presented.

	Frequency response at 18 kHz r(18 kHz)	Frequency responses at 120, 200 and 364 kHz r(120 kHz); r(200 kHz) and r(364 kHz) respectively	Relationship r(120 kHz) : r(200 kHz) : r(364 kHz)
Variability of fish length (28 to 42 cm)	4.5 dB	3.5 dB	
Variability of surrounding seawater temperature (8 to 12 deg.)	6 dB	2 dB	no sensitivity to flesh!
Variability of fat content of flesh (5 to 30 %.)	no sensitivity	5 – 20 dB (depends on the sound speed contrast)	
Variability of the sound speed contrast of shear waves (0.1 to 0.9)	no sensitivity	15 – 20 dB	

Table 1. Results of the sensitivity analysis for frequency response of mackerel.

Backscattering by herring.

It was demonstrated in (Gorska and Ona, 2003, a, b) that for shallow depths, the
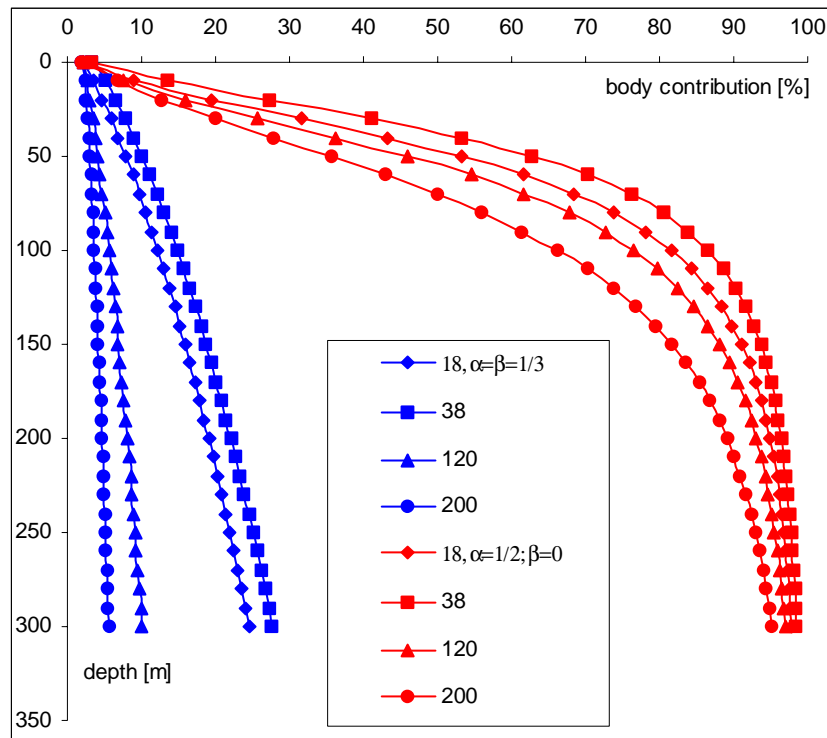

Fig. 2.

Contribution of herring flesh to the backscattering of whole fish.

backscattering by the swimbladder is dominant at all commonly used echo sounder frequencies, but the relative importance of the body increases with depth due to the compression of the swimbladder.

The backscattering from the fish body as a proportion of the whole-fish backscattering (the ratio of the flesh backscattering cross-section to the whole fish backscattering cross-section) is presented in Fig. 2. The blue and red curves corresponds to the different swimbladder contraction rates, $\alpha = \beta = 1/3$ and $\alpha = 1/2$, $\beta = 0$ respectively (α and β are the contraction rates for the width and length of swimbladder respectively, see Eqs. (13) and (14) in (Gorska and Ona, 2003a)). Differently marked curves within each colour group refer to various frequencies, as indicated in the legend. The calculations relate to herring of mean total length 32 cm, with a swimbladder length 0.26 times the total length, and mean dorsal widths of swimbladder and fish body 10 mm and 20 mm respectively. The fish length distribution is unimodal with 10% standard deviation. The density and sound speed contrasts used were (1.04; 1.04) and (0.00129; 0.23) for fish body and swimbladder, respectively. We used orientation distributions with a mean of 0° and standard deviation of 5°. Summarising the results presented in the figure, the contribution of herring flesh is sensitive to the acoustic frequency and to the nature of the swimbladder deformation. The faster the dorsal cross-section of swimbladder is reduced, the larger the contribution. It was also demonstrated (not presented here) that the contribution is controlled by the spread of the tilt angle distribution of herring. The larger the width, the smaller was the contribution.

The results of computed frequency response at different depths, as compared with the measured frequency response are demonstrated in Fig. 3.
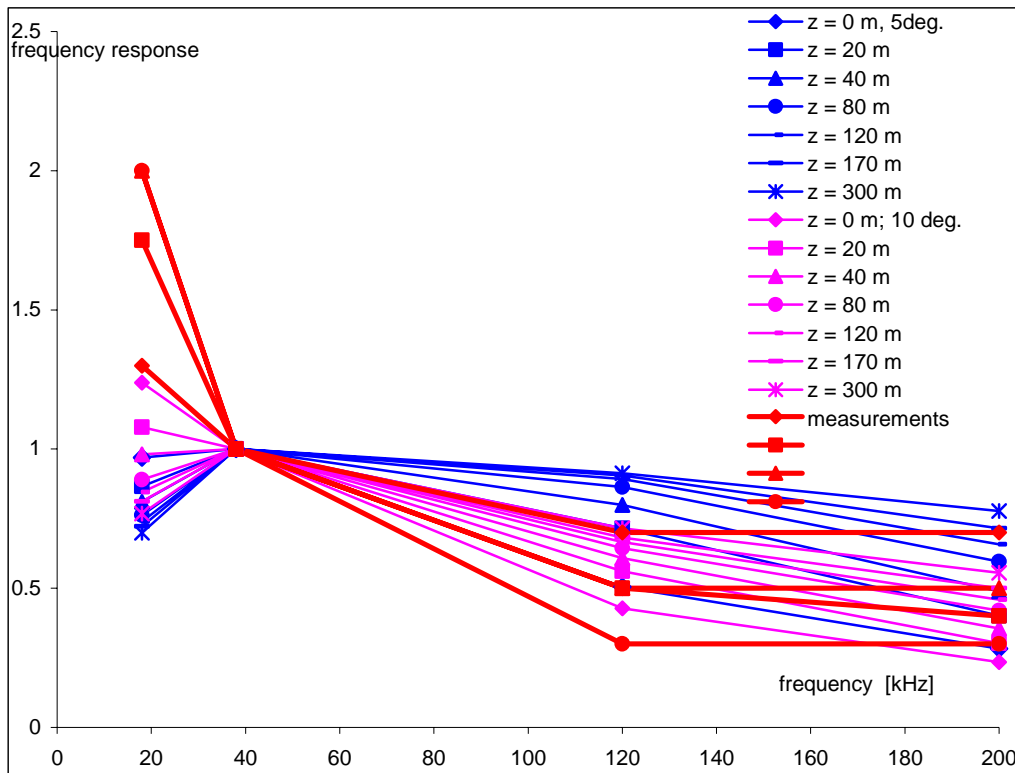

Fig. 3.

Comparison of measured and computed frequency response for herring.

The blue and pink curves correspond to the different widths of the tilt angle distribution of herring, using 5 degree and 10 degree respectively. Different curves within each of group refer to various depths, as it is indicated in the legend. Computations were made for $\alpha = \beta = 1/3$. The other parameters are as for Fig. 2. The modelling demonstrates a clear sensitivity of the frequency response to depth and the spread of the tilt angle distribution. It was also shown that the how the swimbladder contracts, will influence the depth dependence of frequency response.

The measured frequency response is marked with red. Some similarity can be remarked between measured and theoretical curves. This supports our present interpretation of the backscattering mechanism for herring.

Backscattering by pout.

Because of the sparse data on pout morphology and behaviour and lack of the measured, clean data on the frequency response, we have only made some early predictions of the possible shape of frequency response for pout. The results of the calculations are presented in Fig. 4. Different curves refer to different total lengths of pout and different width of its orientation distribution. These are indicated on the right hand within the figure. The calculations relate to pout with a swimbladder / total length ratio of 0.26, with a mean dorsal width of 10 mm. The fish length distribution is unimodal with 10% standard deviation. The

density and sound speed contrasts for fish swimbladder are (0.00129; 0.23) respectively. The tilt angle distributions used were $N(0^o,5^o)$ and $N(0^o,10^o)$.
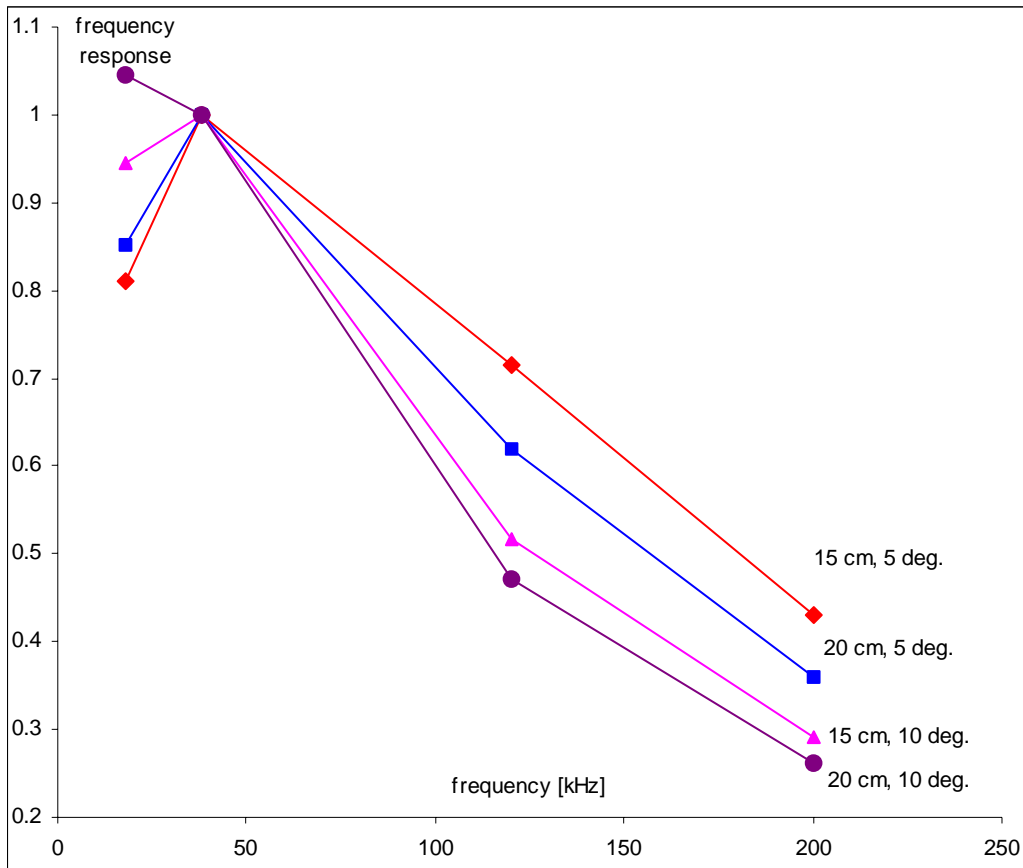

Fig. 4.

Computed frequency responses for Norway pout.

CONCLUSIONS

When summarising, we can conclude that the obtained results confirm that the specific character of the frequency responses for herring and mackerel are strongly connected with the different backscattering mechanisms for these two species. The modelling and the comparison of its results with the measured data are very effective for explaining the observed frequency response. It is also a justification for multi-frequency identification techniques.

As it was shown in the previous section, theoretical interpretation of the measured frequency response is not complete (see Figs. 1 and 3). We have not yet explained exactly the observed frequency response for mackerel and herring using modelling However, the development of multi-frequency methods for fish species identification requires more accurate justification. To do this we should understand the reasons of disagreement between theoretical and experimental results. A few reasons may be mentioned:

It is important to note that for mackerel the significant reason of the disagreement is that only the backscattering by flesh and backbone of mackerel has been considered. However, the backscattering by the other bones, like the head bones can also be important at higher frequencies.

The other reason is that backscattering is shape-dependent phenomenon. However, in our models the simplified shapes for herring body and swimbladder and for mackerel backbone were applied. It means that high-resolution models, accounting for the actual shape of different fish parts should be developed and used. Short-range, tank measurements with wideband transducers may also be considered.

The sensitivity analysis demonstrated that for mackerel the frequency response is sensitive to the sound speed contrast and density contrast of the flesh as also as sound speed contrasts of the compressional and shear waves and density contrast inside the backbone. For herring the sensitivity of the frequency response in regard to the width of the orientation distribution and compression rates of swimbladder dimensions was also shown. Therefore, for the accurate explanation of the frequency responses, data on these controlling parameters should be collected for herring and mackerel. Measurements of such parameters are strongly recommended for further developing multi-frequency fish identification algorithms.

It is also important to mention that for herring, more accurate comparison of modelled and measured frequency response should be done at different depths. This would be useful for our interpretation of the impact of the herring behaviour and swimbladder compression on its frequency response.

Otherwise, the paper demonstrates clearly the effectiveness of a modelling approach in the interpretation of the observed frequency response. In the following use of a larger frequency spectrum in echo sounders, acoustic modelling may serve as a guideline for interpretation of the results. The three species analysed here can now easily be identified and separated in new synthetic echograms, and hence measured. If totally mixed in the same school, however, trawl sampling is still needed.

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