Multifrequency scattering properties of herring (*Clupea harengus*) and Norway pout (*Trisopterus esmarkii*)

Rita Santos, Norma García-Núñez, Sascha Fässler, and Paul G. Fernandes


The accuracy of acoustic surveys for the estimation of fish resources can be compromised by uncertainties associated with the identification of echotraces to species. This study aims to determine the multifrequency scattering characteristics of echotraces of the pelagic species, herring (*Clupea harengus*) and Norway pout (*Trisopterus esmarkii*) which co-habit similar areas of the North Sea in summer. These species are acoustically quite similar: both possess swimbladders; both occur in densely packed schools close to the seabed; and the schools are similar in shape and size. As a result, their echotraces have traditionally been difficult to distinguish. Norway pout, however, usually much smaller than herring in size, such that their frequency specific acoustic signature may differ. The scattering properties at different frequencies are, therefore, possible important discriminating characteristics which could lead to an algorithm for the identification of each species. Data were taken from the International North Sea Herring Acoustic Surveys, in the summers of 2000, 2001 and 2002. The data comprised of mean volume backscattering strengths (MVBS) at 18, 38, 120 and 200 kHz from a scientific echosounder, ground truthed with samples taken from a pelagic trawl. Positional, morphological and energetic features of the echotraces were examined using a clustering technique indicating that the statistical characteristics of the energetic variables provided the best discriminating capacity. However, no significant signature was found to distinguish between the species. Indications are that a more thorough analysis of echotrace parameters in conjunction with environmental covariates may prove more useful in discriminating between these two species.

Keywords: Acoustics, multifrequency, identification, herring, Norway pout.

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Introduction

Acoustic techniques have become an important part of many stock assessments aiming to determine the abundance and distribution of fish (MacLennan and Simmonds 1992). This is especially true for abundant pelagic species such as herring (*Clupea harengus*), which usually form large schools in midwater and can be detected effectively by echosounders, providing information that is vital to assessments (Simmonds 2003). As a means to estimating abundance, acoustic surveys are an efficient tool as they offer almost continuous detection of objects in the whole water column, at a very high resolution (typically 20 cm in the vertical), over large distances. This has distinct advantages over point sampling techniques such as trawls.
However, the objects detected still require identification and this is usually carried out by “ground truthing” using other samplers such as trawls (McClatchie et al. 2000).

The acoustic data are arranged as two dimensional slices of the water column - echograms. Individual fish schools are detected as echotraces and these provide a variety of descriptive features. These features can be extracted using three different approaches: analysis and classification of the whole echotrace e.g., its height, length, position, shape etc. (LeFeuvre et al. 2000); analysis of the echo-amplitude distribution within a shoal - the amplitude Probability Density Function (PDF) approach (Scalabrin et al. 1996); and analysis of the amplitude characteristics by examining data from numerous simultaneously operated echosounder frequencies (Korneliussen and Ona 2002).

A number of studies have considered echotrace classification: see Reid (2000) for a review. Coetzee (2000) used a shoal analysis and estimation system (SHAPES) to characterise sardine schools. Lawson et al. (2001) combined the SHAPES system with discriminant function analysis to classify and assign morphometric attributes of fish schools, such as school height, depth or width, which differed between schools of different species. Although these methods can obtain a classification success of up to 96% in monospecific situations, it is generally thought that the information available at a single frequency is rarely sufficient to deal with more complex realistic situations (MacLennan and Holliday 1996). Additionally, classification can be quite inaccurate without appropriate corrections of the descriptors extracted from acoustic images. Corrections are often needed for school geometry (Diner 2001) and bottom detection (MacLennan et al. 2004).

The use of more than one frequency in an acoustic survey can give more biological information and improve the accuracy of the scrutinising process, especially if the acoustic properties of individual species vary with the frequency in use (Madureira et al. 1993). Such techniques have been used to discriminate between groups of fish, micronekton and zooplankton and also for discrimination between biological targets and physical phenomena such as bubbles (see Horne 2000). Korneliussen and Ona (2002) used multi-frequency processing techniques to distinguish between various different targets such as mackerel, swimbladdered fish, and zooplankton. A similar approach was used by Kloster et al. (2002) to identify and distinguish between three dominant deep-sea fish groups. The difference in mean volume backscattering strength (ΔMVBS) between frequencies was described by Kang et al. (2002) as one of the most promising methods for acoustic species identification. If nothing else, the technique has been recommended for not being as subjective as visual classification (Watkins and Brierley 2002).

Despite these advances, the practice in acoustic surveys with regard to target identification is still based on visual interpretation or scrutiny (Reid et al. 1998) aided by trawling (McClatchie et al. 2000). The International North Sea Herring Acoustic Survey (Bailey et al. 1998) is one such example. The north west component of this survey, which accounts for over 90% of the adult biomass (ICES 2004) encounters few major identification problems. The one difficulty that is encountered, is distinguishing between echotraces of herring schools from those of Norway pout (Trisopterus esmarkii). In recent years, multifrequency data has been collected during these surveys. The aim of this paper is to analyse these data, as well as several positional, morphological and energetic features of echo-traces from the herring and Norway pout schools in the North Sea during this survey. A clustering technique was applied in order to determine which parameters might be helpful for discriminating between the species. Multifrequency scattering levels were then examined, with significant effort being applied to ensure comparability between frequencies. Ultimately the goal was to determine which parameters might be sufficiently different between the two species in order that a species identification algorithm might be constructed.

**Materials and methods**

**Data collection**

Data were taken from the Scottish component of the International North Sea Herring Acoustic Surveys, in the summers of 2000, 2001 and 2002, carried out on the Fisheries Research Vessel (FRV) *Scotia*. FRV *Scotia* is responsible for the north-western part of the area, which covers ICES Division IVa. Further details of survey procedures can be found in individual survey reports (e.g. ICES 2004).
Acoustic data were collected using a Simrad EK500 scientific echosounder (Bodholt et al. 1989), operating three transducers at frequencies of 38, 120 and 200 kHz; and a Simrad EA500 echosounder, adapted for scientific research, operating at 18 kHz. The EK500 transducers were located adjacent to one another (within 0.5 m) on the drop-keel of the vessel and were deployed approximately 3 m below the hull. The 18 kHz was hull-mounted just over 5 m directly forward of the other transducers. The echosounders were configured to ping simultaneously at each frequency every second, with pulse lengths of 0.7, 1.0, 1.0 and 0.6 ms at 18, 38, 120 and 200 kHz respectively. The performance of the echosounders was monitored using standard target calibration techniques (Fernandes and Simmonds 1996). The acoustic data were collected from 03:00 to 23:00 hrs.

Data were logged from the echosounder to a personal computer with SonarData’s Echolog software (SonarData Pty Ltd., GPO Box 1387 Hobart, Tasmania, Australia). The raw data were collected as echogram (Q) telegrams consisting of time stamped digitised volume backscattering strengths (VBS). Each pixel on the echogram, therefore, corresponds to a VBS (symbol, $S_v$; unit, dB re $1m^{-1}$). Other telegrams collected include detected seabed depth and geographic location (latitude and longitude).

Major echotrace concentrations were sampled with a pelagic trawl with a net of 20 mm mesh in the codend. When trawling at a speed of approximately four knots the trawl’s vertical opening was 12 metres and the horizontal opening was 20 m. Trawl catches provided information on catch composition in numbers, latitude and longitude, time of start and end for the haul, as well as other parameters such as depth trawled and a description of the fished echotraces. Data from a total of 141 trawl hauls were examined from the three surveys: 70 trawl hauls were composed exclusively of herring and 8 trawls exclusively of Norway pout. Other trawls hauls contained a mixture of these and other species.

**Acoustic data analysis and corrections**

SonarData Echoview was used for the analysis of the echosounder data. Using the positional information from the trawl haul, polygons (“sampols”) were constructed to delimit the areas on the echograms sampled by the trawl. Echoview’s schools module, based on Barange’s (1994) SHAPES algorithm, was then used to detect schools and make measurements of school descriptors. Only the ‘identified’ echotraces, contained inside the “sampols” were considered. These detected and identified echotraces were then divided into four categories: pure herring (100%), mainly herring (>70%), pure Norway pout (100%); and Norway pout and herring in a mixture.

The characteristics of the 18 kHz transducer (specifically its 11° beam) and more significantly, its position on the hull of the vessel 5 m ahead of the other transducers, required corrections to be made to the positions of the data, so that the data from four frequencies could be comparable. The general philosophy adopted was to attempt to align isolated distinctive echotraces in the two datatsets (hereafter referred to as EA data for the 18 kHz and EK data for the 38, 120 and 200 kHz).

A vertical offset of approximately 3 m was applied to the EA data in order to match the vertical position of echotraces. The seabed on the EA data was then adjusted to be equivalent to that detected by the 38 kHz in the EK data. In some cases, the border that defined the detected echotrace on the EK data did not match with a whole ping on the EA data. This was presumably due to a drift in clock times between the two systems. Echoview’s Match Ping Time operator was applied to correct this. This operator selects pings from the first operand in such a way as to match the times of the pings in the second operand. The EA data echotraces had an additional horizontal displacement compared to the EK data (due to the alongship displacement and to occasional significant time mismatches). Echoview’s Ping Time Shift operator was applied, shifting the time on each ping to either the time of the prior or following ping. The procedure was repeated until the position of the echotrace on the EA data matched the position of the equivalent echotrace on the EK data.

To account for the different beamwidths in the two systems, Echoview provides echotrace statistics corrected according to Diner (2001). In addition, image analysis techniques were applied to isolate the kernel of the school as recommended by Korneliussen et al. (2004). An erosion filter (Reid and Simmonds 1993) was applied replacing each data point with the minimum value of the data points in the
surrounding cells: effectively this reduced all echotrace boundaries by one pixel. Schools were then detected on the eroded data and the new ‘eroded’ boundaries were used to create an alternative dataset (see Fig. 1).

Cluster analysis

In a first approach, clustering techniques were used to analyse several positional, morphological and energetic features of echo-traces from herring schools in the EK data. This particular analysis was confined to EK data as the positional and morphological parameters should not have been influenced by frequency, but would be seriously influenced by the change in beamwidth and transducer position. A large number of variables were extracted but those which were highly correlated were removed leaving: MVBS, NASC (Nautical Area Scattering Coefficient), mean height, length, mean depth, latitude, longitude, area, volume, and the coefficient of variation of VBS.

The clustering technique employed was the k-means method (MacQueen 1967) using the K-means2 program (pers. comm. Dr. Pierre Legendre, Université de Montréal). In this method the number of clusters (k) can be determined as part of the clustering procedure, or specified in advance. The advantage of this is that the schools were known to belong to one of four classes (herring, mainly herring, Norway pout and a mix) and so the clustering method - naturally, without being given this information - would hopefully apportion schools into these four categories. One disadvantage of the method, however, is the requirement for balanced datasets. The number of school echotraces available for each species category differed markedly, with more than 70% consisting exclusively of herring. Therefore, “herring” and “mainly herring” data were randomly sub-sampled in order to balance the species category composition of the database (Table 1).

The algorithm operates in three stages as follows. The data are arbitrarily placed into k initial clusters. Euclidean distances are calculated between the variables, and for each of the clusters a mean distance (centroid) is computed. The data are then taken in turn, and placed into the cluster whose centroid is closest to its distance. New centroids will then be calculated for the cluster which receives the item, and for the cluster that loses it. This process is repeated until there are no more reallocations of the data. In the course of the iterations, the aim is to minimise the sum, over all clusters, of the squared within-group residuals, which are the distances of the objects to the respective cluster centroids. Convergence is reached when the objective function (i.e., the residual sum-of-squares) cannot be lowered any more. The clusters obtained are such that they are geometrically as compact as possible around their respective centroids (Legendre 2001).

The number of initial clusters (k) was altered from k=4 to 10 with the optimum number being determined by examination of the Calinski and Harabasz pseudo-F-statistic (Calinski and Harabasz 1974). Once every object was assigned to a particular cluster, the species category composition of the cluster was compared with the expected species composition (4 classes of known species composition) using a chi-squared test. Every set of clusters was then plotted (using boxplots) against each of the variables used for the clustering analysis, to see which variable had the biggest influence in the clustering procedure. In cases where specific clusters had a predominant percentage of a species category and boxplots showed noticeable differences in the distribution of such clusters, data were tested for normality and one-way ANOVA tests were performed to assess the statistical significance of the differences.

<table>
<thead>
<tr>
<th></th>
<th>Herring</th>
<th>Norway pout</th>
<th>Mainly herring</th>
<th>Mixture of herring and Norway pout</th>
<th>Total</th>
</tr>
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<td>144</td>
<td>142</td>
<td>144</td>
<td>30</td>
<td>460</td>
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<td>705</td>
<td>68</td>
<td></td>
<td></td>
<td>773</td>
</tr>
<tr>
<td>Eroded</td>
<td>293</td>
<td>52</td>
<td></td>
<td></td>
<td>345</td>
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</tbody>
</table>

Table 1. Number of school echo-traces used for the analyses as indicated. Cluster = balanced datasets for k-means clustering algorithm from 38, 120 and 200 kHz; Scatter = number of whole echotraces for scattering level measurements from 18, 38, 120, 200 kHz; Eroded = number of eroded echotraces for scattering level measurements from 18, 38, 120, 200 kHz.
Scattering properties of herring and Norway pout

Scattering levels

Further analysis considered only the energetic parameters of the echotraces from the pure herring and pure Norway pout categories (Table 1), and included the corrected EA data (18 kHz). Frequency specific scattering levels at the four frequencies were compared by examining the corrected Mean Volume Backscattering Strength (MVBS,) and the MVBS of the eroded echotraces, of both species. MVBS_c provides a correction to account for the different beamwidths (Korneliussen et al. 2004). Differences between the mean values of these variables for each species were tested using a Mann-Whitney test (Zar 1984) at each frequency. The coefficient of variation of MVBS_c for the original (whole) echotraces was also examined. Other energetic parameters (volume backscattering coefficient and NASC) were found to show the same trends as MVBS.

In addition, the frequency specific characteristics of each echotrace were compared using two measures, the dB difference, ΔdB, and the frequency response, r(f) (Korneliussen and Ona 2003), where:

\[ \Delta dB = \hat{S}_v(f) - \hat{S}_v(38) \]  
\[ r(f) = \frac{\hat{s}_v(f)}{\hat{s}_v(38)} \]

and:

\[ \hat{S}_v = \text{mean volume backscattering strength of the echotrace (dB)} \]

\[ \hat{s}_v = \text{mean volume backscattering coefficient of the echotrace (m}^{-1}) \]

Figure 1. Processing steps to produce eroded echotraces which define the “kernel” of the school. a) Original echotraces of two fish schools; b) Same fish echotraces after applying a 3x3 erosion, shown inside the borders of the original detected echotraces; c) eroded schools with new detected borders; d) original echotraces with borders of the eroded “kernel” shown. Dotted lines indicate how the borders of the echotraces line up ping to ping.
These measures are actually equivalent, as $S_v = 10 \log_{10} (S_v)$ (MacLennan et al. 2002), such that $r(f) = 10^{\Delta dB/10}$. Naturally, comparative scattering profiles using one or the other can look quite different according to the scales used.

**Results**

A total of 22 iterations were carried out for the k-means clustering with $k=4$ returning a Calinski and Harabasz pseudo-F-statistic of 94.2. Other values of $k$ returned lower values of this statistic; $k=4$ also returned the largest sum of squared euclidean distances between clusters (40.89). The species composition of the echotraces apportioned to the $k=4$ clusters is rather good (Fig. 2). There are two clusters (1 and 2) with over 75% herring; one cluster (3) with 81% Norway pout; and one cluster (4) with a mixture. This broadly reflects the original composition of the schools and a chi-squared test comparing the original species composition with that given by the clusters gave a moderate result ($X^2 = 103.16, P>0.01$). However, it should be noted that the number of schools in the predominantly Norway pout cluster (3) was small (total of 27), and that most (81) of the Norway pout schools were allocated to cluster 4, which is a mixture. When examining the variables associated with the clusters only the coefficient of variation of MVBS at 38 kHz showed a significant effect (ANOVA, $F_{1,918}=2075, P<0.05$) on the assignment of species categories into the different clusters (Fig. 2). Clusters 1 and 2 (herring) had lower CVs than cluster 3 (Norway pout), with cluster 4 (mixture) having intermediate CVs. This indicates that high MVBS CVs are associated with schools of Norway pout. None of the other variables examined showed a similarly coherent pattern (i.e. of different values for cluster 3, similar values for clusters 1 and 2, and intermediate values for cluster 4).

In the second phase of the analysis, the results of the comparisons of scattering levels indicate that both herring and Norway pout have very similar trends in scattering levels at the four frequencies studied (Fig. 3): MVBS$_c$ in both species were highest at 18 kHz and lowest at 120 kHz. Herring had higher mean MVBS$_c$ as well as the largest range of MVBS$_c$, compared to Norway pout: however, this difference was only significant at 120 and 200 kHz (Mann-Whitney, $p<0.05$) and not significant at 18 and 38 kHz (Mann-Whitney, $p_{18kHz}=0.20, p_{38kHz}=0.07$).

When considering the eroded echotraces, the trends according to frequency of herring and Norway pout MVBS were also similar (Fig. 4). However, at all frequencies values of herring and Norway pout were significantly different (Mann-Whitney, $p<0.05$). The eroded herring echotraces exhibited a smaller range of scattering levels at all frequencies compared to the range of MVBS$_c$ for non-eroded echotraces; those for Norway pout were similar.

The decibel difference ($\Delta dB$, Equation 1) of the mean MVBS values for eroded and non-eroded schools showed similar trends according to frequency for both species. For the non-eroded echotraces, both species had positive values at 18 kHz and negative values at 120 kHz (Fig. 5). The absolute difference in dB between the mean values at 18 and 38 kHz were $+2.01$ and $+1.56$ for herring and Norway pout respectively. Another point to note is that on average, herring had a positive $\Delta dB$ at 200 kHz, whereas Norway pout had a negative one.

These patterns were similar in the eroded echotraces (Fig. 6), however, the range of $\Delta dB$ for eroded schools was smaller than for the non-eroded schools. A further difference observed was that the $\Delta dB$ at 18 and 200 kHz were both negative for both species in the eroded echotraces: in the non-eroded echotraces $\Delta dB$ for both species was positive at 18 kHz.

Examination of the frequency response ($r(f)$, Equation 2) yielded identical patterns, which is not surprising given that the measure is equivalent according to $r(f) = 10^{\Delta dB/10}$. However, the presentation of this statistic is different (Fig. 7 and 8), particularly at low values of $r(f)$ (negative $\Delta dB$). The non-eroded echotraces showed the highest $r(f)$ values at 18 kHz compared to the three other frequencies for both species. The highest variability in $r(f)$ was observed at 18 and 200 kHz in non-eroded echotraces. Eroded echotraces had a much narrower distribution of $r(f)$ values at all frequencies. Eroded schools also had a lower $r(f)$ at 18 and 200 kHz respectively compared to the non-eroded schools, resulting in a much more homogenous $r(f)$ at all frequencies.

Analysis of the coefficient of variation of eroded echotraces was also considered as the cluster analysis indicated that this variable might be capable of discriminating between the two species. However, results showed that herring
and Norway pout presented similar CV values for the three years surveyed.

Fish length compositions of herring and Norway pout were also considered. The length distribution of these two species were different, with Norway pout being smaller. Given this, it might be expected that a distinction between the two species could be obtained by comparing the size specific scattering levels. However, in the present case at least, length was not found to be an influencing factor.

**Discussion**

This study describes the multi-frequency scattering properties of herring and Norway pout, with a view to establishing differences which might be used to discriminate the two species. Based on energetic characteristics, herring and Norway pout seem to have similar scattering levels at frequencies of 18, 38, 120 and 200 kHz. This fact might make these two species distinguishable from groups of other fish species, which are expected to have a different response to the same frequencies. Nevertheless, differentiation between herring and Norway pout still represents a problem because of the similarity observed in their acoustic responses.

Nero et al. (2004), compared measured scattering levels with values from theoretical scattering models in herring, at high (38-200 kHz) and low (1.5-5 kHz) frequencies. A distinct resonance peak (intense scattering) was observed at 2.5 kHz. At higher frequencies, scattering values decreased, reaching a minimum VBS at 38 kHz for measured values and at 90 kHz for model values. In the present study, a similar trend was observed in the high frequency

**Figure 2.** Results from the k-means clustering analysis. Top: percentage (with number inside the bars) of schools allocated to the k=4 clusters according to the known species composition (herring, mainly herring, Norway pout, and a mix), e.g. Cluster 1 was composed of 104 (44%) herring schools, 79 (34%) mainly herring schools, 36 (15%) Norway pout schools, and 15 (6%) mixed schools. Bottom: Boxplot of the coefficients of variation (CV) of the mean volume backscattering strengths at 38 kHz for all schools in each cluster. Cluster 3 (composed of 81% Norway pout) had the highest mean CV; clusters 1 and 2 (78 and 86 % herring respectively) had the lowest CVs; whilst cluster 4 (47% Norway pout, 45% herring ) had intermediate CVs.
Figure 3. Mean values of MVBS with 95th and 5th percentile and maximum and minimum values, for herring and Norway pout non-eroded echotraces. The values for Norway pout are slightly shifted along the x axis for clarity.

Figure 4. Mean values of MVBS with 95th and 5th percentile and maximum and minimum values, for herring and Norway pout eroded echotraces. The values for Norway pout were shifted along the x axis for clarity.
Figure 5. Mean values of decibel difference (ΔdB) with 95th and 5th percentile for herring (top) and Norway pout (bottom) non-eroded schools. The MVBS decibel difference is expressed in relation to 38 kHz.
Figure 6. Mean values of decibel difference ($\Delta dB$) with 95th and 5th percentile for herring (top) and Norway pout (bottom) eroded schools. The MVBS decibel difference is expressed in relation to 38 kHz.
Figure 7. Mean values of relative frequency r(f) with 95th and 5th percentile for herring (top) and Norway pout (bottom) non-eroded schools. The frequency response is expressed in relation to 38 kHz.
Figure 8. Mean values of relative frequency r(f) with 95th and 5th percentile for herring (top) and Norway pout (bottom) eroded echotraces. The frequency response is expressed in relation to 38 kHz.
domain, however, minimum values occurred at 120 kHz.

Herring and Norway pout were the main source of scattering in the samples. Although Norway pout was caught in smaller numbers, and their length composition was smaller than herring, they had strong echoes. Since there was not a big overlap in the size distribution of Norway pout and herring, it might be expected that a distinction between the two species could be obtained due to the weaker reflecting properties of the smaller fish. However, results showed that in the present case, length was not a factor influencing echo strength.

Differences between mean VBS in herring and Norway pout may be influenced by erroneous allocation of species to the supposed ground truthed echograms (Bethke et al. 1999). For instance, in some cases, information on the echograms might not have corresponded exactly with data on the matching trawl, either by not sampling the whole school, or targeting a different school. As in every acoustic fish survey, the assumption made that haul composition represented the echotrace composition is uncertain.

A decrease in variability of VBS between non-eroded and eroded echotraces was observed, for both species, at all frequencies, for both $\Delta dB$ and r(f). This can certainly be associated with the erosion process which removes smaller values and results in a much narrower range of data. The resulting significant difference of VBS values at 18 and 38 kHz between eroded Norway pout and herring schools can be explained by the erosion process which separates the mean values further. However, despite these differences being statistically significant, they are unlikely to be useful as a discriminator due to the large overlap. An algorithm which use morphological and positional parameters, in addition to these subtle differences might therefore have some merit.

Although the clustering analysis indicated that the CV of MVBS may be useful, the data eventually used was probably too unrepresentative, as many echotraces had to be removed in order to achieve a balanced dataset. Other methods, which are not sensitive to this limitation should be explored. Comparisons of CVs for the entire dataset of the energetic variables did not indicate significant differences. This may be due to the use of eroded schools which reduces variability as described above.

Identification of these two species will continue to be dependent on the knowledge and experience of the observer and on directed trawl samples. For the survey area considered in this study, Norway pout is often found on rocky substrates at shallower depths less than 100 m, whereas herring is commonly found in soft bottoms at deeper depths from Norway pout (E.J. Simmonds, FRS Marine Laboratory Aberdeen pers. comm.). A system which incorporates bottom typing, may therefore have some merit.

In a fisheries context, aggregation patterns have changed historically in relation to stock level, exploitation pattern and the environment (Reid 2000). These factors might be influencing the shape of school echotraces in the area surveyed, as the species abundance in the surveys have been quite variable through the years. Recent data on Norway pout and herring abundance were not reported in this study but it is known from a recent survey (pers. obs. 2004) that herring abundance continues to be high while there were no records of Norway pout. Further studies will be hampered by a lack of such data.

Conclusion

Herring and Norway pout schools had similar scattering levels at frequencies of 18, 38, 120 and 200 kHz. Scattering was generally highest at 18 and 38 kHz, and always lowest at 120 kHz for both species.

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