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Improved fish detection in data from split-beam sonar

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Abstract − Hydroacoustic split-beam techniques have been applied to enumerate salmon migrating in the river Tana (northern Norway) during the summers 1998 and 1999. Analysing data by single echo detection and tracking was difficult. Missing echoes in tracks from fish, combined with noise in the output from the single echo detector was seen as reasons for this. An improved counting method is presented. Contours from moving targets are detected by image analysis. Then, detected single echoes within these contours are combined into tracks. This procedure reduces problems related to noise, and to tracking fish with few accepted single echoes. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

horizontally scanning sonar / fish detection / image analysis / single echo detection

Résumé − Amélioration des détections de poissons à partir des données de sonar à double faisceau. Les techniques hydroacoustiques à double faisceau ont été appliquées pour le comptage de saumons en cours de migration dans le fleuve Tana, dans la partie nord de la Norvège, durant les étés 1998 et 1999. L'analyse des données de détection d'échos individuels apparaissait difficile. Des échos manquants dans le suivi d'échos de poisson, combinés aux bruits lors de la réception du détecteur d'écho individuel sont les raisons principales. Une méthode améliorée de comptage est présentée. Les contours des indices de réflexion des cibles en mouvements sont détectés par analyse d'image. Puis, des échos individuels, détectés à l'intérieur de ces contours, sont combinés en traces. Cette procédure réduit les problèmes liés aux bruits et ceux liés aux suivis des poissons avec seulement peu d'échos individuels retenus. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

sonar horizontal / détection de poisson / analyse d'image / détection d'échos individuels

1. INTRODUCTION

Hydroacoustic split-beam techniques have been applied to enumerate adult Atlantic salmon (*Salmo salar*) migrating in the river Tana (northern Norway) during the summers 1998 and 1999. Data from the fixed, horizontally aligned transducer were analysed by single echo detection (SED) and tracking (Xie et al., 1997). Analysing data with this method proved more difficult than expected.

Missing detection of echoes from fish, and uncertainty in position estimates in echoes accepted by the SED were two reasons for this. Another reason was noise. The SED accepted echoes from unwanted targets and from variations in the background reverberation level. Other scientists have reported similar problems. Noise from surface, bottom and background reverberation has been treated by Kubecka (1994). At the Riverine Sonar Workshop in Seattle (February 15–17), Dawson et al. (2000) discussed variability in the split-beam angular measurements. *Figure 1ab* demonstrates differences between echo-signals from fish recorded in a lake and in a river, while *figure 2ab* demonstrates missing detection of fish by the SED.

The automatic tracking algorithm tended to generate fish-like tracks from noise echoes and to split tracks from fish. This resulted in overestimates. With manual analysis SED, echoes are combined into tracks and counted by a person. This method was found labour intensive and subjective. It was difficult to detect echoes from fish when these were surrounded by noise, and different persons tracking the same data

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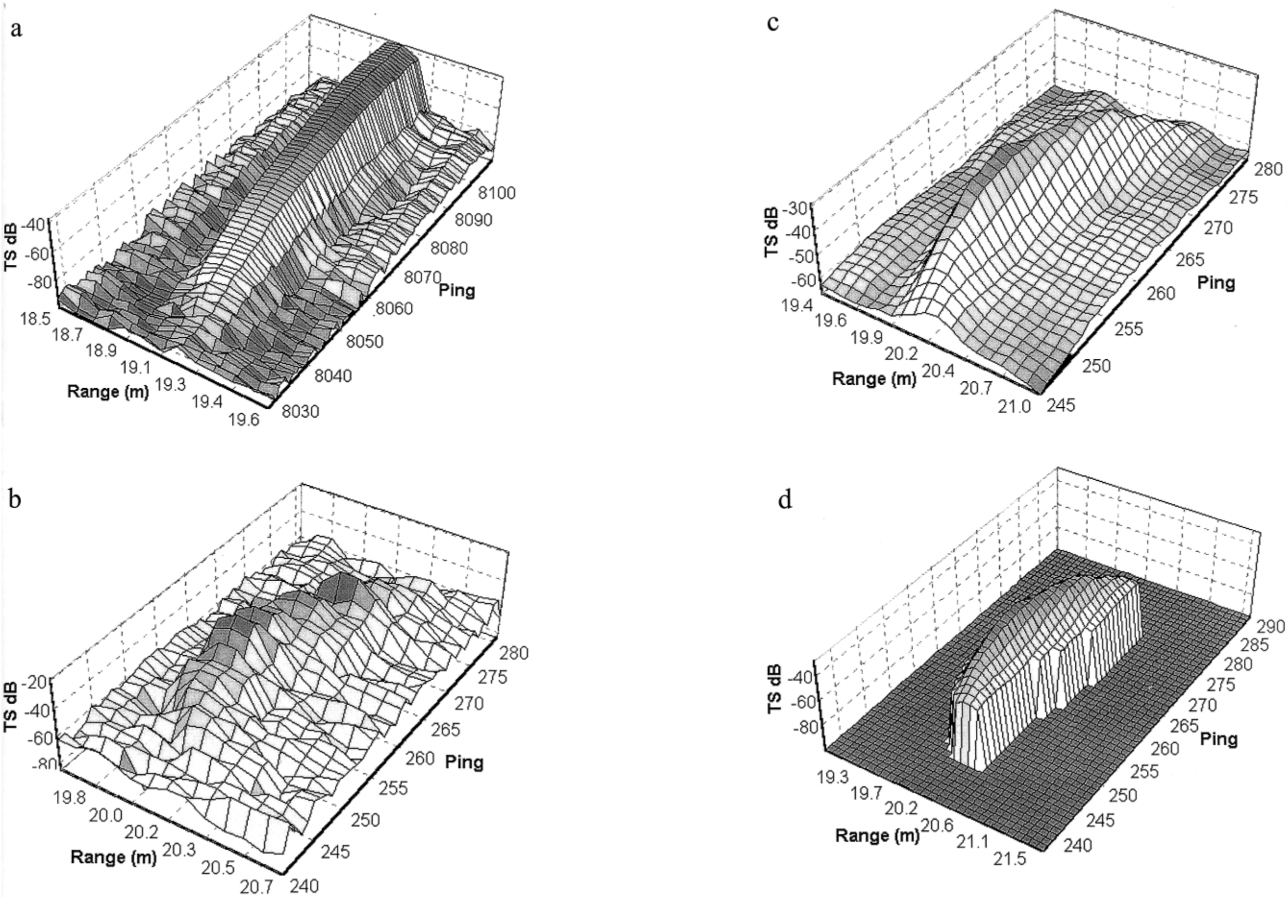

Figure 1. Echograms in 3 dimensions showing fish entering the beam; a) Vertical record taken under the ice in the lake Semsvann southern Norway spring 1998; b) Horizontal record taken in the river Tana summer 1999; c) Result of a filtering the horizontally recorded echogram by a 3×7 mean filter; d) Segmenting the filtered echograms. The echograms in a and b demonstrate the lower signal to noise ratio, the higher fluctuation in the reverberation level and the less stable target strength in the echoes from the river compared with the lake.

tended to get different results. Improving the automatic analysis method was seen essential for further applications of hydroacoustics in Tana.

The split beam transducer is composed of four separate units. These units are arranged geometrically so that both intensity and angles can be detected from the received echo signal (Brede et al., 1990). The amplitude of the echo signal from successive sound transmissions (ping) can be displayed in time/range diagrams (echogram). In order to detect echoes from single fish SED are often applied. Echo pulses accepted by the SED are described with amplitude, time and angular position. Such echoes can be displayed in echograms and position diagrams. In order to distinguish between the two types of echograms, SED and Amp will be used as prefix.

With split-beam echo sounders, a commonly used single fish analysing method is the method based on SED and neighbourhood tracking (Anon., 1999). The SED uses a set of criteria, such as pulse-length and pulse-shape, to decide whether a pulse originates from a single or a multiple target. A fish passing by the sonar will be hit by successive sound-pulses, resulting in a trace of echoes in the echogram. These echoes will be located close in time and position. Combining echoes based on such closeness is commonly coined neighbourhood tracking or window tracking (Anon., 1999).

Image analysis is a field that has grown considerably during the past decade. Image processing has found a significant role in scientific, industrial, biomedical and space applications (Pratt, 1991). In the field of hydroacoustics, image processing has been applied in ocean fisheries for detection and classification of fish schools (Lu and Lee, 1995). In this paper, image analysis is applied to detect moving single targets that pass side-looking sonar in shallow rivers. This is done stepwise by a series of image enhancement and segmentation operators (Niblack, 1986).

2. MATERIALS AND METHODS

Test data has been recorded by an EY500 scientific echo sounder from Simrad AS. The main set of data

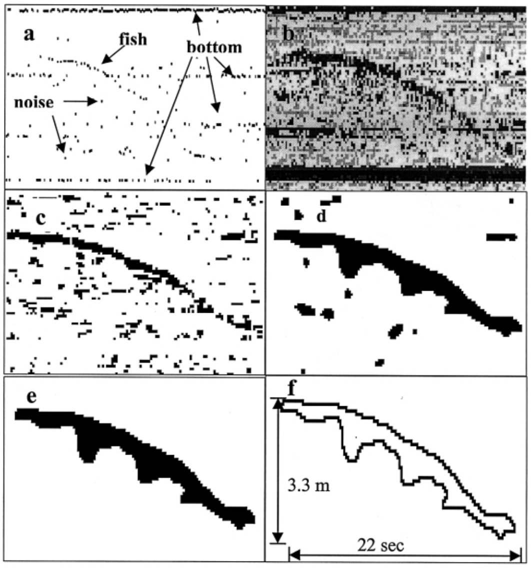

Figure 2. Image processing used to detect a fish with low signal to noise ratio; a) SED-echogram; b) Amp-echogram; c) Output from a mean 1 × 3 filter and adaptive threshold; d) Output from a median 3 × 3 filter followed by a growing operator. Note the reduction in the ping-gaps and the reduction of noise regions; e) Output from the perimeter filter; f) Contour detection. Filter dimensions in c and d are noted as height × width. This fish passed the sonar in Tana July 19, at 17 h 06, at a mean range of 44 m.

was recorded in the river Tana (northern Norway), summer 1999. Here an ES120-4 split-beam transducer was mounted horizontally on a tripod equipped with a pan/tilt rotor. The rotor was built for this purpose at the University of Oslo. The tripod was placed 30 m from the west riverbank at a water depth of 2.8 m, with the transducer 1.3 m above the bottom. The transducer was tilted 2° downwards. On the selected site, the river was 257 m wide and had a sandy bottom with few stones. The bottom inclined smoothly within the transducer range, from 2.8 m to 4.3 m within the 50 m range of the beam. The pan was adjusted so that the beam was pointing normal to the water current, which had a measured speed of 0.19 $m \cdot s^{-1}$. Ping rate was set to 5 $ping \cdot s^{-1}$. The Amp-echogram resolution in the range domain was 9 cm. Video recordings showed that nearly all upstream migrating fish were salmonids, mostly Atlantic salmon, mixed with some trouts.

Vertical sonar recordings were taken on the ice of the lake Semsvannet (southern Norway) spring 1999, and used to compare signal and background noise levels (*figure 1*). In order to get a broader test basis, data collected by other scientists was applied. Two vertically recorded files, one from lake d'Annecy in France, and one from a reservoir in the Czech Republic, were selected. So was a horizontally recorded file from the river Numedalslågen in southern Norway.

A software program 'Sonar5' was developed with Borland's Delphi/Pascal compiler (Miller et al., 1997). Interactive and automatic methods for studying and tracking split-beam data were implemented.

2.1. Single echo detection (SED)

The SED applied in these tests was the detector included in the EY500. The SED parameters used in Tana were: minimal value = –40 dB, minimal pulse length = 0.6, maximal pulse length = 2.8, maximal beam comp. = 6, maximal phase dev. = 10 and one single peak. Transmitted pulse length was 0.3 ms. The pulse length values are given relative to the transmitted pulse length. The pulse length is measured at a 6 dB level below the maximal peak of a pulse. A single peaked pulse is defined as a pulse with no local minimum lower than 1.5 dB relative to the surrounding. Maximal phase dev. parameter relate to standard deviation in the electrical sample angles by a factor of 180/64.

2.2. Neighbourhood tracking

The applied neighbourhood tracking-algorithm worked like this: any SED-echo found in the first ping was established as a new track and noted in a list. Then a range of ± 20 cm (neighbourhood) relative to the position of the last stored echo was searched in the next ping. The closest echo found in this neighbourhood was added to the track in the list. If one echo was found within the neighbourhood of two different tracks, the echo was given to the closest track. Echoes not found within any neighbourhood were added to the list as new tracks. If no echo was found within 6 following pings (maximal ping-gap) after the last echo in a track, this track was defined as completed. Tracks with less than 4 echoes (minimal track length) were discarded as noise. These tracking parameters were found by studying the manually detected fish tracks from the test data. More sophisticated algorithms applying angular positions, varying the neighbour region with missing ping and estimating expected positions for new echoes were tested. With low SNR these algorithms did not track substantially different than the selected algorithm. It was therefore decided to apply the simplest method.

2.3. Developing a new counting method

In order to develop an automatic counting method suited for shallow rivers, the collected sonar data was studied. Amp and SED-echograms were compared. Two important observations were made.

1) The SED removes information from the sonar data. Background reverberation, bottom and multiple echoes are removed. With the EY500 the width and shape of accepted single echoes are also removed. By comparing Amp and SED-echograms from shallow rivers we found that it was generally easier to track fish in the Amp-echogram. Here fish-tracks did not suffer from holes or ping-gap due to missing detection in the SED. Noise pulses was found less disturbing to the human

eye. Echoes from unwanted targets like stones and boat-wakes could easily be identified when the complete echo-signal was available and not only limited to pulses accepted by the SED.

2) The second observation was that the horizontally recorded echo signals could be divided into three main groups. Each group appearing with significantly different intensity/shape signatures. These groups were a) echoes from passing objects, b) echoes from stationary phenomena and c) echoes from stochastic noise.

Echoes from passing objects could be seen as short tracks in the time domain, often with characteristic changes in range related to the geometry of the beam. Stationary phenomena generated thin horizontal lines in the Amp-echogram. These lines changed with changed transducer tilt and were believed to originate from bottom reflections. The last group is seen as clouds of scattered noise pulses. The amount of these pulses increased during periods of rain and wind and they where more frequent at longer range. Sources might be air bubbles, reflections from the surface or sound generated directly in the river. It is reasonable to assume that fish only should be associated with the first group, and it is therefore not important to find the causes for the echoes in the latter two groups. Examples of all three echo-groups can be seen in *figure 2ab*.

The first observation suggests that the Amp-echograms should be applied in the analysis. The second observation indicates that it could be worth trying to detect echoes from the first group and to suppress echoes from the two latter. Regarding the Amp-echogram as an image, techniques from the field of image processing can be applied. Filter operators and segmentation algorithms was implemented in the Sonar5 program and tested against the recorded Amp-echograms. A combination of routines capable of detecting the perimeter of passing targets was found by repeated tests.

A SED was applied to find the movements of the detected targets. Angle data from accepted single echoes within the detected regions were then used to calculate direction and speed. Targets seen with upstream movements were counted as fish.

3. RESULTS

Two basically different image analysing methods were tested, the edge method and the level method. With the edge method, the echograms are treated with high-pass filters. These filters are applied to detect changes in the intensity. With low fluctuations in the background level and in the inner parts of the objects, the boundaries of the object should be detected. We found that the general level of fluctuations in the sonar data was too high for this type of operators. Most high-pass filters produced echograms not readable by the human eye. One exception was the gradient filter that managed to highlight some tracks (*table I*).

Level based segmentation methods seemed to work better. This method uses low-pass filters and threshold techniques to separate tracks from the background noise level. The dimension of the filters was found to be important. In the test data most tracks from passing objects were observed with more or less horizontal orientation. Using a wide but short filter (e.g. 7 pings × 3 samples) on these tracks removed noise without removing tracks (*figure 1c*). Using a narrow but tall filter (e.g. 1 ping × 15 samples) was seen to remove both noise and tracks.

The noise level in the test data varied strongly with time and range. The application of a constant threshold level did not manage to separate tracks from the background noise level. An adaptive threshold method measuring the noise level locally and adjusting the threshold according to the changing background noise was found to work quite well. Regions with intensity 6 dB above the surroundings were found in this way (*figure 1d*). Most of the resulting regions proved to contain echoes from moving and static objects, but some regions with scattered noise were also detected.

Analysing the shape of these objects revealed differences between the groups. Regions with noise were found to have shorter perimeter, smaller areas and larger height/width ratios than the two other groups. Static objects were seen with longer perimeter than moving objects. The application of a filter removing regions having short or long perimeter was seen to differentiate the three echo classes well. Perimeter is here measured as the number of samples found along the border of a detected region. The meaning of long and short will vary depending on the range and time resolution in the echograms and on the average transit time for passing objects. Moving objects in our data were well detected with perimeter lengths between 20 and 500 samples.

Cracks in the detected regions were a problem, but the application of a growing operator, i.e. increasing the size of each region, proved to close most of the observed cracks. A similar effect was seen with low-pass filters.

Qualitative evaluation of the responses from the tested image operators on echograms is given in *table I* while *figure 2* demonstrates detection of a fish surrounded with scattered noise and echoes from bottom structures. In this example both a mean and a median filter has been applied at different stages in the process. Generally the following set of operations was found to work well with the recorded sonar data. a) low pass mean filter with dimension 1 × 3, b) adaptive threshold, c) perimeter filter accepting perimeters between 20 and 500 samples and d) growing operator increasing regions horizontally with 6 pings and vertically by 2 samples. Combined with SED and movement calculations this set of operators was applied to count fish in the collected sonar files. The steps in this procedure are showed in *figure 3*. Manual count was applied as reference for the ‘true’ number of detectable fish. The files were also analysed by the SED/

Table I. Qualitative evaluation of the image operators effect on echograms.

Operators	Type	Eval.	Comments
Mean filter	low-pass	+	Well suited for noise reduction in echograms before segmentation. Some success with ping-gap filling after segmentation.
Pyramid filter	low-pass	–	Same results as the mean filter but weaker and more difficult to use. Pyramid filter is a weighted mean filter.
Median filter	low-pass edge preserving	+	Good noise reduction and ping-gap filling performances in segmented echograms. Computationally demanding.
KNN filter	low-pass edge preserving	–	Difficult to find parameters and dimensions that manage to treat a wide range of track types. The filter algorithm replaces the output echo value with the mean value found from the k-nearest neighbours (k is a user given integer).
Sigma filter	low-pass edge preserving	–	Difficult to find parameters and dimensions that manage to treat a wide range of track types. The filter algorithm replaces the output echo value with the mean value calculated from the echo values found within a range around the filter matrix centre value.
Gradient filter	high- pass	–	Seen to remove time range variations in the background reverberation level. Vertical gradients seen to highlight horizontal tracks. Produces interesting results, but seems difficult to use. The filter detects the first-order derivatives.
Laplace filter	high-pass	–	Not well suited. There is too much variation in the reverberation level for this operator to work. The filter detects the second-order derivatives.
Segmentation	edge-based	–	Too much variation in the echograms. Method not well suited. Works by linking parts of edges detected by high pass filters.
Segmentation	threshold based	+	Well suited to separate tracks from the background noise level. Based on low-pass filters and adaptive threshold.
Hit and remove	morphological filter	–	Can be used to remove short noise pulses. Searches a predefined pattern and removes echoes when found.
Hit and add	morphological filter	–	Can be used to fill ping-gaps in tracks from fish. Searches a predefined pattern and adds echoes when found.
Grow	morphological operator	+	Well suited to fill ping-gaps in segmented echograms. Increases the size of detected regions by adding echoes along the border.
Shrink	morphological operator	–	Can be used in combination with growing operators to gain more distinct tracks when filling ping-gaps. Reduces the size of detected regions by removing echoes along the border.
Perimeter-filter	morphological operator	+	Well suited to remove small regions with echo pulses from stochastic noise and bottom-structures. Should be used in combination with growing operators. The filter removes regions with short and long perimeters. Short and long are defined by the operator.

neighbourhood method to show the performance relative to the manual and the image method. Count results are showed in *table II*.

Manual count resulted in 198 fish-tracks. The result from the image count was 210 fish and the neighbourhood method detected 6 743 tracks. Relative to the results from the manual count an accuracy of 94% was achieved by the image analysis method. The SED/neighbourhood method achieved 3% accuracy.

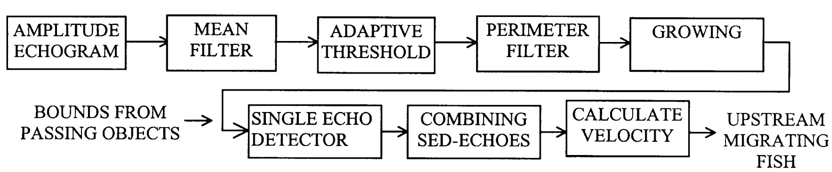

Figure 3. Counting method using image analysis operators. This method was used to produce the results showed in *table II***.**

Table II. Counting results from manual tracking, image tracking and neighbourhood tracking.

Sonar file name	Duration (min)	Transd. aiming	Location	Manual count	Image count	Neighbourhood count
08141313.dg9	11	vertical	reservoir, Czech Republic	7	8	37
09292220.dg7	2	vertical	lake d'Annecy, France	50	50	53
06242218.dg6	40	horizontal	river Numedal, Norway	26	28	360
07191222.dg9	25	″	river Tana, Norway	7	8	408
07191248.dg9	25	″	″	1	2	384
07191313.dg9	25	″	″	7	6	406
07191339.dg9	25	″	″	2	3	400
07191405.dg9	25	″	″	5	6	400
07191430.dg9	25	″	″	4	4	356
07191456.dg9	25	″	″	8	8	361
07191548.dg9	25	″	″	2	3	391
07191614.dg9	25	″	″	11	13	413
07191639.dg9	25	″	″	9	9	368
07191705.dg9	25	″	″	9	11	323
07191731.dg9	25	″	″	3	5	352
07191756.dg9	25	″	″	10	10	323
07191822.dg9	25	″	″	12	11	352
07191848.dg9	25	″	″	7	9	346
07191913.dg9	25	″	″	4	4	366
07191939.dg9	25	″	″	14	12	344
Total	478			198	210	6 743
Total accuracy				100%	94%	3%

4. DISCUSSION

The application of manual counting as a reference for the accurate number of detectable fish-tracks is somewhat speculative. Manual counting is regarded as subjective and inaccurate due to variation in the counter's concentration and interpretation of the echograms. Fish tracks with low signal to noise ratio can easily be overlooked. However with small data sets and with the benefit of using both the Amp and SED-echograms, manual counting can be quite accurate. It is possible to maintain a high and steady concentration during the short counting time. The test data was counted three times, each time giving the same result. It is also important to note that the manual counting does not necessarily reflect the actual number of fish having passed the site where the transducer was placed. This does not interfere with our results because we are evaluating different data analysis methods and not the overall performance of the hydro-acoustic method.

In *table II*, high correlation is seen between the manual and image count in all files. This show that the image-based method is capable of analysing both vertically and horizontally recorded sonar data. With the SED/neighbourhood method this is different. The method seems to apply fairly well to vertically recorded data with high signal to noise ratio (SNR) and good result is achieved with the file from lake d'Annecy. With the Czech file the overestimate is caused by fractionated fish tracks. With the horizontally recorded files the overestimates were caused mostly by generation of noise-based tracks. Reducing the ping-gap parameter reduced the overestimate, but then tracks from fish were overlooked.

In this study fish-tracks were separated from drifting objects simply by checking the movement relative to the water current. Only target moving upstream was classified as fish. Down moving targets will therefore probably be a mixture of fish and drifting debris. Differentiating objects with the same movement is difficult and has not been an objective in this study.

Image analysis is a broad subject. With the many different operators available, it is not possible to test all combinations. During this study we have seen many different operators and combinations of operators give interesting results. It is essential to underline that the presented method only represents one possible way, not necessary the best. The availability of the many image analysis operators provides a high degree of flexibility and makes it possible to adapt the method to many kinds of sonar data. A disadvantage with this flexibility is that it becomes time consuming and difficult to tune the method. Care has to be taken when selecting types and dimensions of operators.

5. CONCLUSION

Image analysis was found to be an effective tool when working with split-beam sonar data. The application of filtering techniques was seen to improve the readability of the recorded echograms. Noise could be suppressed and fish-tracks could be made easier to see for the human eye. Image analysis was also found capable of detecting single passing targets. In combination with traditional single echo detection, this could be used to form an automatic counting method. When applied to the recorded sonar data, good agreement with the fish-count from manual analysis was achieved.

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