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Seasonal variability in cod target strength

Egil Ona

The acoustic target strength of adult cod (*Gadus morhua*) was measured *ex situ* in a large, 4500 m^3, experimental net pen at the IMR Austevoll aquaculture station in eight periods between November 1996 and May 1998. A calibrated Simrad EK500 split beam echo sounder was used to collect the acoustic data from a vertically observing transducer, positioned in the middle of the 21 m deep net pen. Groups of about 20 individual cod were transferred from the control storage population in each measurement series, but moved in every other aspect freely within the experimental net pen during the acoustic measurements. Natural variations in gonadosomatic index as well as changes in condition factor from an enforced starvation was monitored and correlated with changes in target strength. A General Linear Model (GLM) was used to estimate the functional relationship between the target strength at 38 kHz and important biological parameters. The significant ones were: Condition factor (CI), Liver index (LI), the spread of the tilt angle distribution (SDTILT), while the gonadosomatic index (GSI) mean swimming angle (MT) and the swimbladder index (SI) was not significant. For cod between 50 and 60 cm size, the target strength relationship is suggested to be:

$$\langle TS \rangle = 20 \log L - 64.0 - 0.099(SDTILT) + 2.44(LI) - 1.86(CI) ,$$

where the effect of tilt angle may be converted to a day/night effect. Under normal liver index and condition factor, the new mean target strength is slightly higher than the one used in the surveys, but correspond well to the experimental nighttime observations. The *ex situ* data are compared with recent *in situ* target strength measurements.

Keywords: Target strength, cod, variability, uncertainty

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Introduction

The North East Arctic cod stock has been monitored acoustically over several decades. Proper acoustic surveys on the younger part of the population started in 1976 and were extended to also include a bottom trawl survey in 1981. The specific acoustic survey methodology used is thoroughly described by Dalen & Smestad (1979; 1983) and generally by MacLennan & Simmonds (1992). The standard methodology used for both surveys are made by Jakobsen et al. (1997), which also includes and a critical evaluation of the surveys. Typically, from 1995 three co-operating research vessels cover the total survey area in the Barents Sea (160 000 nm^2) with a regular grid survey pattern within one month, working about 300 random trawl stations. The integrated acoustic energy from layers identified as cod by trawl samples, are converted to fish density by applying a target strength relation for gadoids, close to the one recommended for gadoids by Foote (1987):

$$\langle TS \rangle = 20\log L - 68.0 \text{ [dB]}, \qquad (1)$$

where <TS> is the mean target strength and length of the fish is expressed in centimetres. The time series of acoustic survey data recalculated according to this relationship from when is was first adopted, in 1993 (see Aglen & Nakken, 1997).

Systematic variations in target strength due to variable behaviour and physiological state of the fish are presumably averaged within the working equation, as Foote (1987) recommended the relationship on the basis of all available *in situ* target strength measurements on gadoid fishes, but forcing the slope of the relationship to 20logL. The slope was evaluated as being more precisely estimated from experimental (Nakken and Olsen 1977; Foote 1980) measurements. Some scattered, more recent target strength work on cod (Rose and Porter (1995) have, at least for sizes between 16 and 70 cm confirmed the estimated slope, but suggested a slightly higher level, -66 as compared to the actual, overall suggestion by Foote, -67.6. Even for juvenile cod, 5.1 and 3.1 cm, ex *situ* and *in situ* data collected suggest to fit this slope at 38 kHz, with a b_{20} of –68.1 to –70.4 (Ona 1991).

In this particular investigation, however, the size dependency is not studied, but is concentrated to one length group of fish. For this group, the potential variations between seasons, both with respect to condition factor and to the development of spawning products was studied. Since cod has a well developed gas secretion / gas resorption systems in its swimbladder (Harden Jones & Sholes (1985), it is likely that cod is close to neutrally buoyant at all depths. The swimbladder volume, and hence its form is therefore assumed to be constant at all depths. Some deviations from this strategy has however been observed during extensive vertical migrations during feeding, where cod seem to prefer to be neutrally buoyant at its upper vertical migration amplitude (Godø & Michalsen, 2000). Uncompensated, the volume of the swimbladder will expand and compress according to Boyle’s law, but only a relatively mild over- expansion (25%) of the volume may result in stretch-damage and eventually, a rupture. It is therefore likely that rapid resorption of gas is the strategy as the fish ascend and gas production is started when the fish descend. The first is a fast process, but the production is slow. Cod may therefore be negatively buoyant in the first hours after descending.

The main factors studied here are the indirect effects condition factor, and gonad development and fat investment (liver index) may have the cod swimbladder. As the swimbladder is responsible for about 95% of the mean backscattered energy from cod (Foote, 1987), this may give an indirect effect on the mean target strength of cod. If surveys conducted on different components of the stock, and on fish of condition status, the potential errors involved may be quantified. From earlier evaluations of natural variations in the swimbladder volume and form, Ona (1990) suggested that these changes could be several decibels in magnitude. Direct measurements have, however not been made. If significant relations between target strength and the studied parameters is found, the bias may be removed if the effect can be included in the target strength relationship. If not accounted for, they will significantly contribute to the total uncertainty of the mean backscattering cross section, and consequently in the estimate of cod abundance.

Material and methods

The experiments were carried out at the fish farming plant of the Austevoll Aquaculture Station, south of Bergen; where about 400 reared cod were kept in captivity over more than two years, from November 1996 to June 1998. The fish was fed with dry pellet (12mm diameter), specially blended for cod. The daily supply varied from 0 to 15 kg depending on the water temperature and the responds of the fish to the feed. The transfer of the fish from the storage pen to the measurement pen was carried out using a scoop net. Typically, about 20 cod were selected to represent the experimental group in each experiment. These were left for more than five hours in the experimental pen to adapt before measurements started. Two net pens, 14 mm meshes, knotless nylon, were used. These were the storage pen, 12x12x7m, and the experimental pen with a dimension of 12.5x12.5x21 m. The water temperature at the experimental site was monitored continuously using temperature sensors installed at 0.5, 5, 10, 15 and 25 m depths. The salinity data was acquired from regular samples taken at the Aquaculture Station. Feeding was stopped 2 days prior to each measurement period, and the fish used for target strength measurements were not fed during measurements, usually conducted over 3 to 7 days.

The experimental set-up used in this study is shown in Fig. 1, with an example of typical registrations of single targets of the cod in Fig. 2. Captive cod were kept in a storage pen on the open seaside of the floating pier, while the measurements were done in a separate, experimental pen on the inner side. Details of the transducer mountings and experimental set-up are earlier described for similar measurements of herring Ona et al. (2001). At the beginning of each measurement period, about 20 cod to be acoustically measured were carefully transferred from the storage pen to the measurement pen using a scoop net. During the measurements, the fish could freely move about in the 4500 m^3 net pen, frequently entering the acoustic beams, which only covered a small fraction of the central volume of the pen.
At the end of each target strength measurement period, the fish were carefully retrieved by slowly pulling the pen to approximately 1 meter below sea surface. If no panic-behaviour was observed, then the fish were individually as groups of three fishes brought up immediately using a scoop net to an anaesthetising container for swimbladder-volume measurement. The anaesthetising solution, a lethal dose, was prepared by adding 25 ml Metomidate solution (1 gram active agent) into roughly 40-litre seawater.
Measurement of swimbladder volume in cod was performed as described by Ona (1990), but slightly adjusted for cod. After opening the body cavity and removal of the intestines, the swimbladder was punctured ventrally with a 1-millimetre diameter, open needle, and while

the gas was collected in an inverted funnel, the ventral swimbladder wall was ventral massage from the front towards the needle.
The length of cod (L) was measured to the nearest centimetre below the total length. The round fish weight (W) and gonad weight (W_g) were measured to the nearest gram.

The condition factor CF , gonadosomatic index , GSI, swimbladder index, SBI, and the liver index, LI was calculated as:

$$CF = \frac{W}{L^3} \times 100 \qquad GSI = \frac{W_g}{W} \times 100 \qquad SBI = \frac{V_{SB}}{L^3} \times 10000 \qquad LI = \frac{W_l}{W} \qquad (2)$$

where V_{SB} is the volume of the swimbladder in millilitres, W_g , W_l and are the weigth of the gonad and liver, respectively.

The Simrad EK500 echo sounder (Bodholt et al. 1989) was used to collect target strength data at three frequencies; 18, 38 and 120 kHz, with transducer nominal beam opening angles of 11, 8 and 9 degrees, respectively. The echo sounder software version was EK500 (V5.3S.), with increased vertical resolution and fixed, common pulse duration. Calibration, target strength measurement methodology and single target recognition criteria, as implemented in the echo sounder, were used as recommended in Ona (1999). The actual sound speed was computed from temperature and salinity recorded, and applied during calibration and measurements.
The filtered and accepted single-fish-echo data were logged via the serial port of the echo sounder and stored on a TCI 486 personal computer, using standard communication software PROCOMM (V2.4, Datastorm Technologies Inc., 1986).

The first step in the data analysis process was the selection of suitable datasets for target strength analysis, mainly based on the appearance of the echograms. Only recordings showing clear single fish traces and suitable fish densities were selected for further analysis. This procedure ensured an extremely low probability for falsely accepting multiple targets, but was generally less a problem during cod measurements compared to similar measurements on herring. Further, one frequency at a time, suitable range–limits were selected to be safely outside two times the transducer nearfield and for isolating false echoes from the net pen. Selected segments of the recordings were run through a target tracking software (Ona & Hansen, 1991) isolating the target strength data from each herring track in separate data blocks. Finally, these data blocks were used to compute the swimming angles of the fish relative to the transducer, data reformatting and for further statistical analysis of target strength. A suitable cut-off beam angle of 5^0 off-axis was selected on the basis of statistical analysis of target distribution within the beam, ensuring a high signal to noise ratio on the targets detected inside this limit.

The average mean-track-target-strength within each time interval was computed in the intensity domain from all accepted, valid measurements made within the time interval. Depending on density, depth and how the cod passed the transducer beam, usually several hundred accepted target strength measurements was recorded each hour. This will hereafter be referred to as the hourly mean target strength, and was later treated as an independent sample of the mean target strength of the fish. For each group of fish, the hourly mean target strengths were further averaged to provide the estimate of its overall mean target strength. On occasions, where less than 50 tracks were detected within one hour, data from adjacent hours were pooled together. A minimum of 50 tracks was chosen to stabilise the variations of each hourly mean estimate. The possible effect of the gonad development, condition factor and tilt angle on target strength of cod was studied using a general multiple linear regression analysis. In order to eliminate or reduce its size dependency, all the hourly mean target strengths ($\overline{TS}_H$) were normalised by the Root Mean Square length (RMS_L) of the fish. The result is the so called b_{20} , as in the equation:

$$TS = 20\log \ell + b_{20}. \tag{3}$$

The specific formula used was

$$b_{20} = \overline{TS}_H - 20\log(RMS\_L + 0.5). \tag{4}$$

The addition of 0.5 cm to the RMS length was due to the fact that the length of the fish was measured to the nearest centimetre below its total length. The length-normalised target strength or b_{20} was then selected as the dependent variable, the swimbladder index (SBI), gonadosomatic index (GSI), Liver Index (LI), Condition Factor (CF), mean tilt angle (Mean_Tilt) and the standard deviation of the tilt angle (SD_Tilt) were the candidates as predictor variables.
After grouping biological data and acoustic data for each period and further merged with all periods to one large file, a Generalised linear model was fitted to the data in the same manner as for similar analysis on herring (Zhao, 1996; Ona et al. 2001).

The starting model used was:

$$\begin{aligned} b_{20} &= \beta_0 + \beta_1(SBI) + \beta_2(CF) + \beta_3(LI) + \beta_4(GSI) + \beta_5(Mean\_Tilt) \\ &+ \beta_6(SD\_Tilt) + \sum_{i=7}^{15}\beta_i(\text{int}\,eraction) + \varepsilon \end{aligned} \tag{5}$$

where β_0 is the constant term, $\beta_1 \ldots \beta_6$ are regression coefficients for the individual predictor variables, β_i is the regression coefficient for the interaction term and ε is a normally distributed error term.

Initially, all the interaction terms, limiting to two variables for each term, were included in the model. A stepwise backward elimination procedure was performed using the General Linear Model option in SYSTAT (1992a). The elimination procedure was started with the interaction terms, and the α-to remove value used was 0.25. At each step, the interaction term that had the highest probability was removed and the revised model refitted. This procedure was repeated until no interaction term that had a probability level greater than 0.25 was left. The inclusion of the interaction terms in the final model was further constrained by a minimum tolerance of 0.1 to prevent the presence of strong inter-correlation between the predictor variables in the model (SYSTAT 1992). The final subset model was then tested at the 5% level.

Results and short discussion

These biological data are summarised for all periods in Fig. 3 and 4. A small growth in length in the cod population is seen from the start of the experiment to the last period. A clear cyclic variation in the condition factor, liver index and in the gonadosomatic index is also seen, Fig. 4. This shows that the enforced feeding regime applied, with respect to daily rations functioned as planned. The mean condition factor was reduced from above 1.5 in March 1997 to 0.9 in August 1997, well correlated with the liver index. Similarly, the gonadosomatic index was at its maximum in March 1997 and in March 1998. Similarly the swimbladder index was fairly constant for all periods, 5-6% of the body volume, except for one very cold period in January 1998, when the fish preferred the deepest part of the net pen, and was adapted here. As the fish was not allowed to adjust to surface level before anaesthetising, the mean swimbladder index recorded here was almost twice its normal value, as expected from the pressure reduction.

Calibration data for each period from December 1995 to June 1998, have been carefully presented by Ona & Svellingen (1998), and show that after the new software of the EK500 was installed, earlier problems with close range calibrations (Ona et al. 1996) was removed. In the period covering measurements of cod, the 38 kHz echo sounder with new ES38DD split beam transducer varied less than 0.5 dB in TS transducer gain, and about 0.1 degree in opening angles, covering a temperature range of 1 – 20 C^{o}. It is therefore assumed that errors from calibrations are less than 0.2 dB with the cut-off angle used.

Since large cod is a directive target at 38 kHz, a fair number of measurements of the backscattering cross section must be sampled in order to obtain a precise mean value. Normally, more than 10000 measurements were collected in each period, but if the data was to be hourly separated, an estimate of how many samples is needed to stabilize the means value may be evaluated from Fig. 5. The estimate will vary with sounder frequency and the activity of the fish, but generally, about 500 measurements seems to be large enough to estimate the mean backscattering cross section with 5% accuracy at 38 kHz. This allow for the possibility of estimating the mean hourly backscattering cross-section, and its corresponding statistics. Similarly, the swimming angle of the fish was estimated by target tracking as described by Zhao (1996) and Ona (2001b), here erroneously called the tilt angle. The exact validity of using the term tilt angle for the swimming angle have not yet been confirmed for cod.

An example of the estimated hourly mean backscattering cross section, and a summarized target strength distribution collected over 40 hours in May 1998 is shown in Fig. 6. Further, a box plot of the mean hourly backscattering cross section (not corrected for fish size) for all eight periods, from Nov. 1996 to May 1998, with the corresponding size-normalized box plot of b_{20} for all periods is shown in Fig 7 a and b. A similar, cyclic variability in target strength as in the biological characteristics is apparent, but with mean target strength well above presently used b_{20} of –68 dB.

To isolate the important terms affecting the mean target strength, the GLM analysis described earlier was made, and the results are summarized in Table. 1. Both the effect of variable swimbladder index, mean tilt angle and the gonadosomatic index was removed as not significant by the GLM analysis, with remaining factors to be condition factor, liver index and spread of the tilt angle distribution. The remaining equation to describe the combined dependency is:

$B_{20} = -64.0 - 0.099(SDTILT) + 2.44(LI) - 1.86(CF)$,

The actual effect is tried visualized in Fig. 8, showing the relation between the target strength and the condition factor, on the exaggerated scale, CF, 0.5 – 2.0. On this scale, the difference between very lean fish of CF=0.7 and fish in extremely good condition, CF=1.4 would be 1.3 dB, with the leaner fish being a stronger target. The effect of liver index is very moderate, and should at a later stage also be removed from the relationship, as it is well correlated with condition factor. One of the larger effects, however, is the effect of spread in tilt angle (or more correctly, the swimming angle). The difference between a typical day and night situation may be evaluated from the difference between the red (night) and blue (day) lines, almost exactly 1.0 dB, when 25 and 15 degrees spread is used. The effect may be studied in more detail from Fig. 9, where the normalized target strength and estimated spread of the tilt angle distribution is shown as a function of observation hour. Although if the data is not corrected for varying day-length in the different period, significantly higher target strength is seen during daytime, here defined as the time between 8 – 18 hours.

At this stage, it is difficult to foresee the direct use of the suggested relationship in practical acoustical work. Firstly, the new relationship suggest that the presently used target strength relationship for cod is slightly too low, and that the constant term should be closer to –66.8 than to –68.0, as presently used. Using normal values for the parameters, (SDTILT= 15.0, CF =0.82, LI = 0.10) results in a typical daytime mean target strength of TS = 20logL – 66.7, and a corresponding –67.8 for night-time registrations. Further, the relationship may be used to evaluate acoustic estimates made on the very starved and lean cod stock in 1986 – 1988, during the collapse of the capelin stock (see Marchall et al. 1999). However, the material is collected on a very limited length group in order to isolate the variability from a selected list of parameters, and the length dependency of the relationship is not investigated here. In the presentation, the data will be compared with recent in situ target strength and target counting methods from the Lofoten spawning ground survey (Aksland, 2005; 2006).

Acknowledgement

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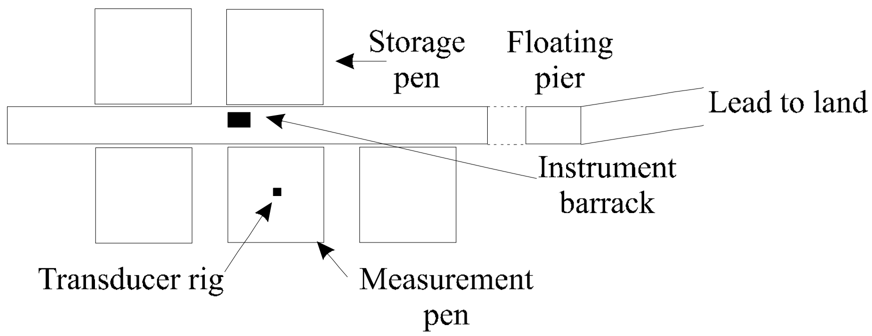
Table 1. The resulting regression statistics for the effect analysis. The subset model was in the form of $\mathbf{b}_{20} = \beta\mathbf{X} + \varepsilon$, where $\mathbf{X}$ denotes the predictor variable vector as listed in the first column, β denotes the regression coefficient vector and ε is the normally distributed error term. Tolerance $=1-r^2$, where r^2 is the squared multiple correlation between one predictor and other predictor variables included in the model. For the regression, $r^2=0.152$, SE $(\varepsilon)=1.70$, $n = 90$, $p = 0.0025$. To study the effect, se Fig. 8.

Variable	Coefficient (β)	SE(β)	Tolerance	P(β=0)
Constant	-64.0	1.13		<0.0005
SD(tilt)	-0.01	0.04	0.96	0.0076
LI	2.44	8.59	0.54	0.0055
CI	-1.86	0.76	0.52	0.0160

A: Plan view



B: Side view

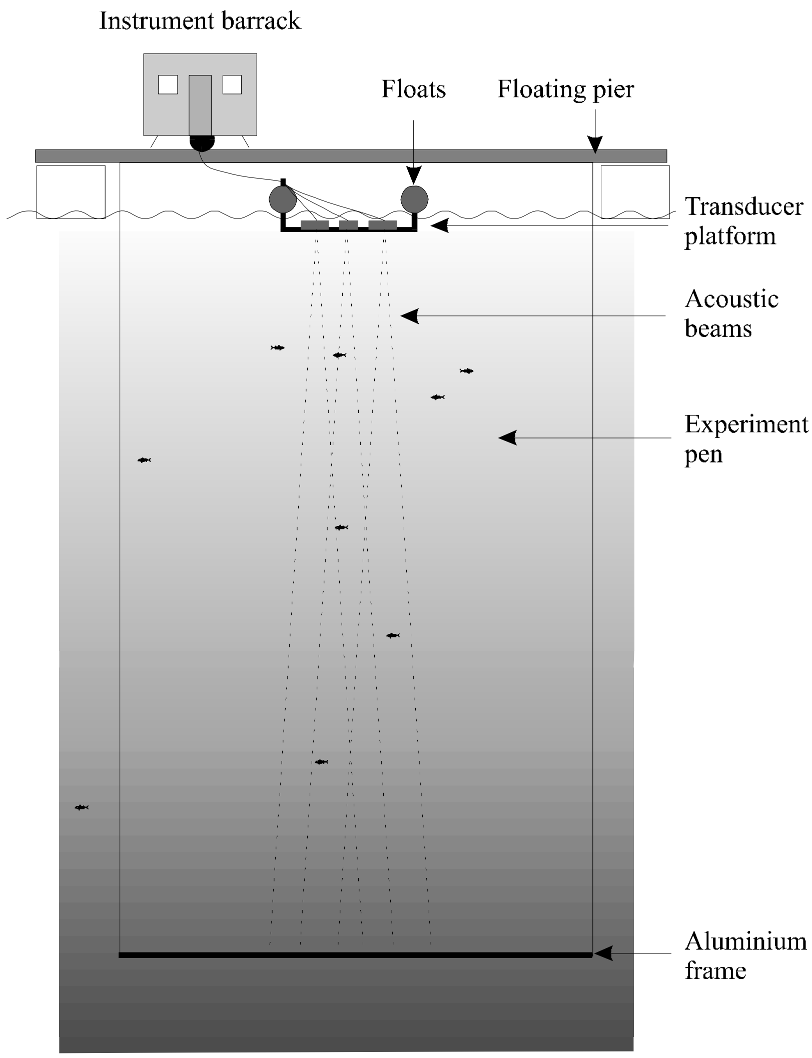


Figure1. Experimental setup during measurements of cod. Transducer platform not to scale. Experimental pen 12.5 x 12.5 x 21 m.

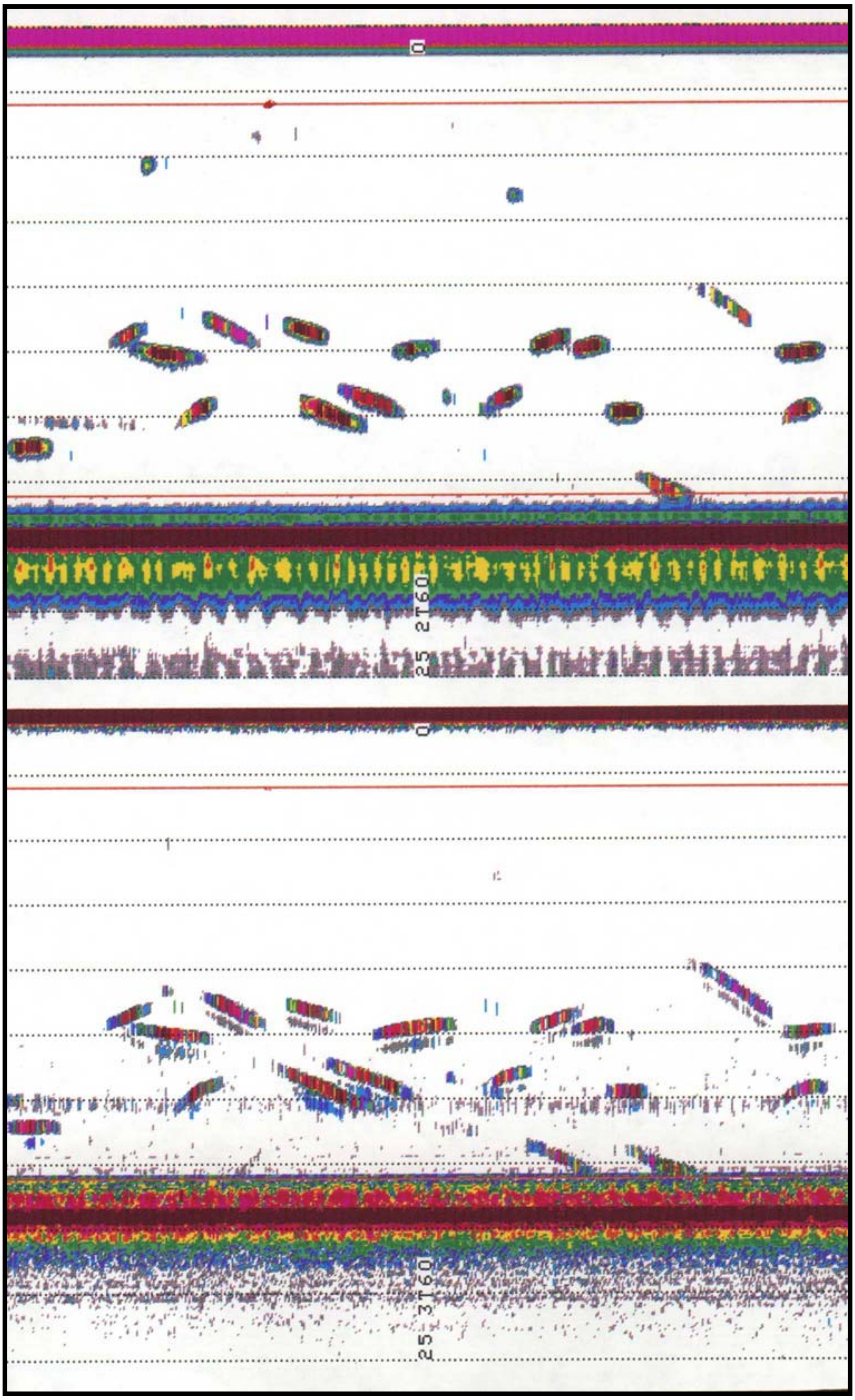


Figure 2. Example of recordings on cod at two frequencies running simultaneously. Total depth scale shown on both are 0 – 25 m. Red lines indicate upper and lower data selection lines..

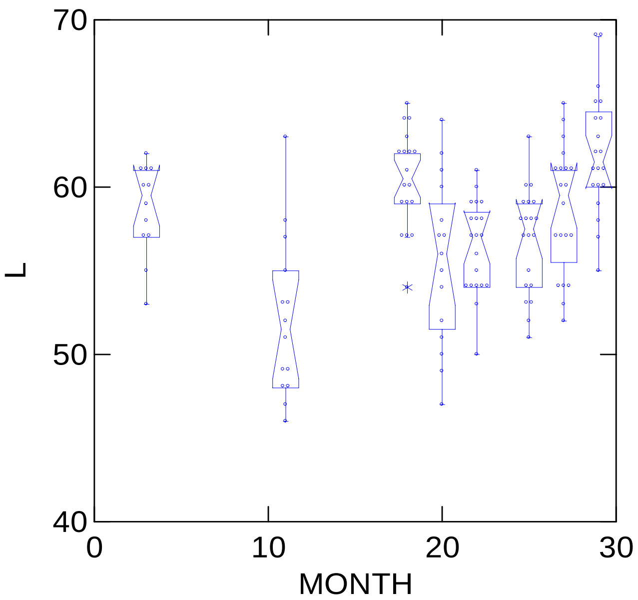


Figure 3. Length distributions of the cod used for target strength analysis from November 1996 to May 1998.

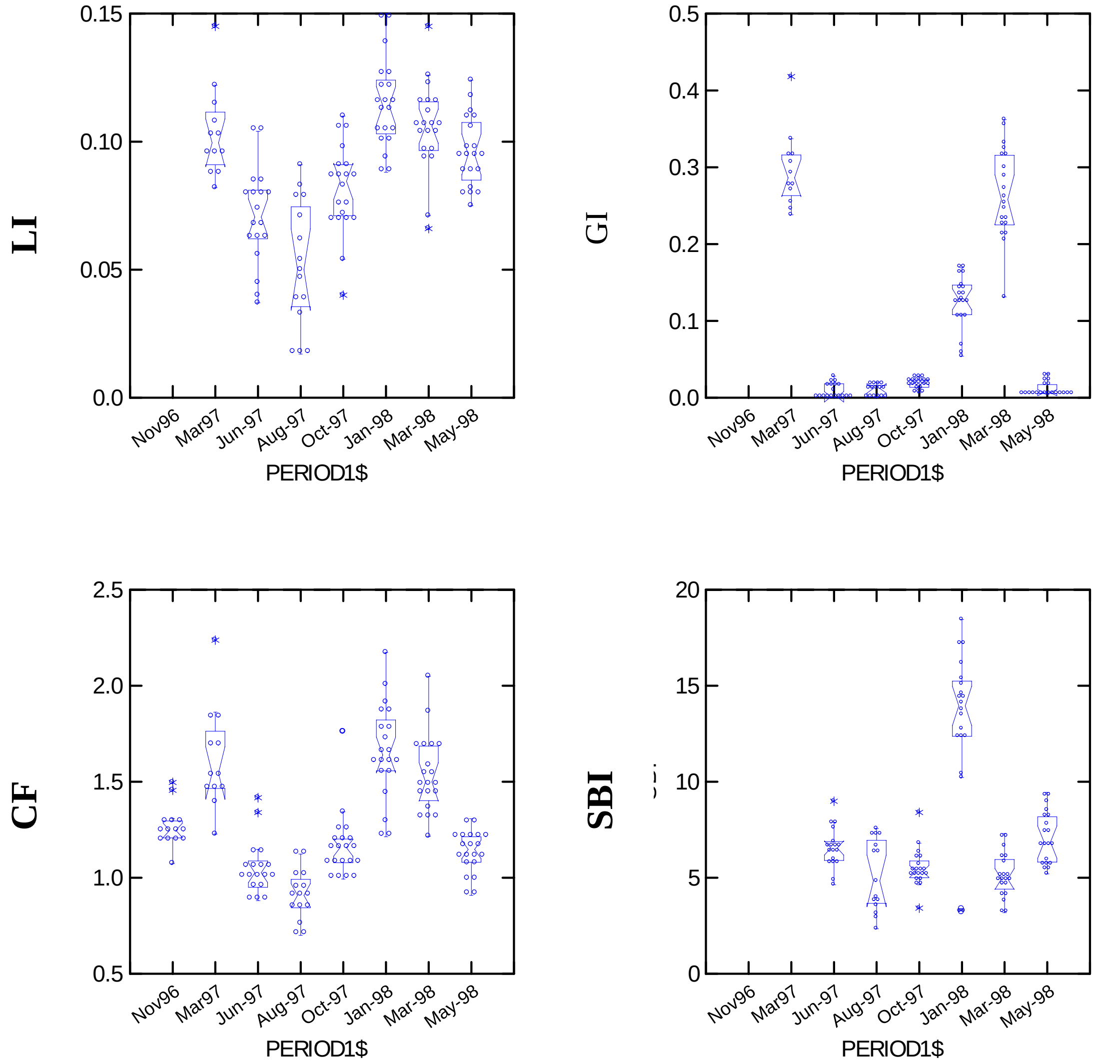


Figure 4. Box plot of important biological study parameters, related to the cod target strength measurements. A: - Liver Index, B: – gonadosomatic index, C: – Condition factor, and D: – swimbladder index.

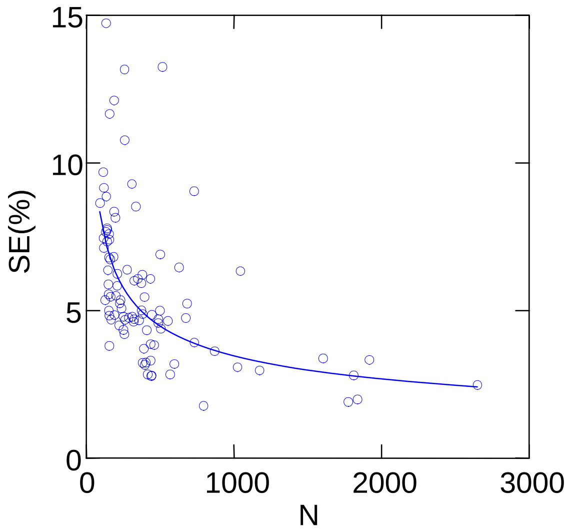
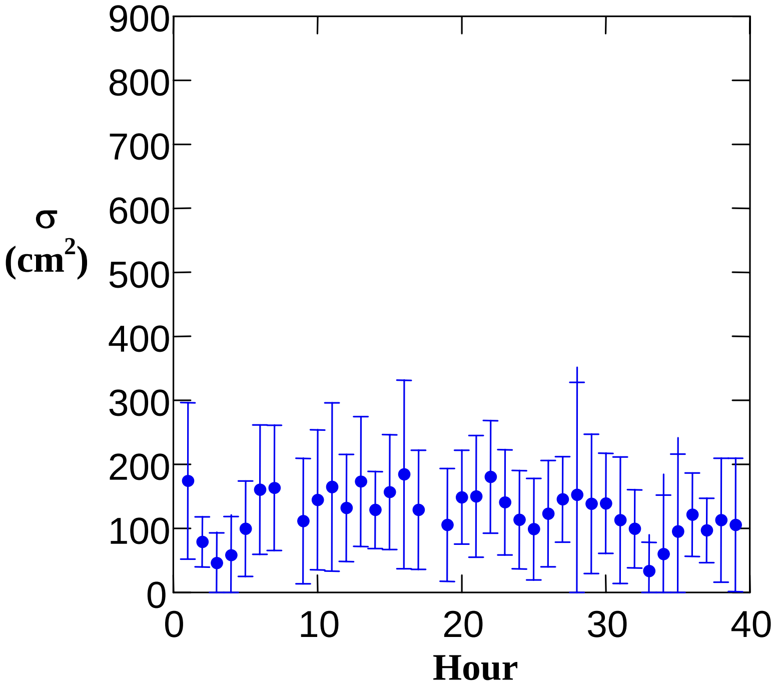


Figure 5. Precisions of the estimated mean backscattering cross section as a function of number of measurements. Results from hourly means on cod, all data are shown, with standard error of the mean, expressed in % of the mean value are shown.



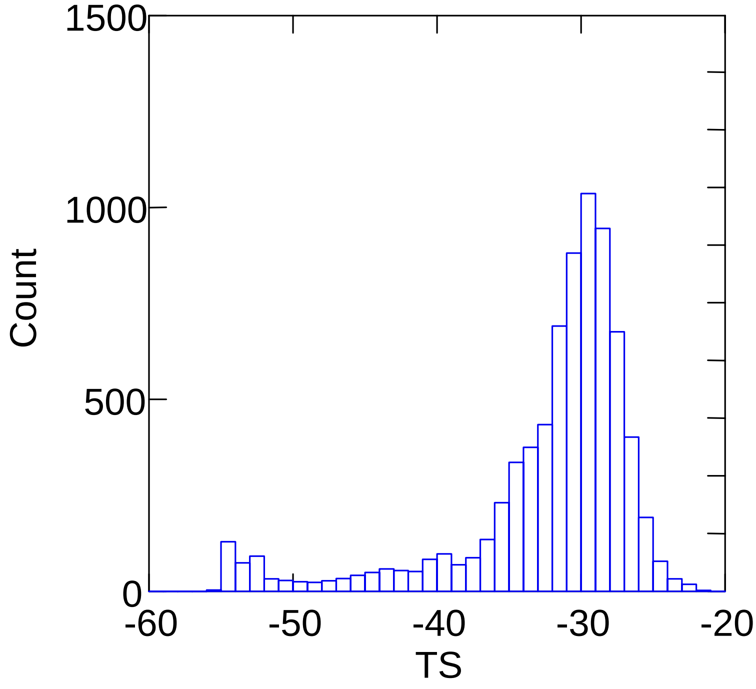


Figure 6. A: Backscattering cross section of cod observed over 40 hours in the May 1998 experiment. Mean and standard deviation is shown. B: Summarised all target strengths measured in May 1998, 7517 accepted data. Mean target strength is shown.

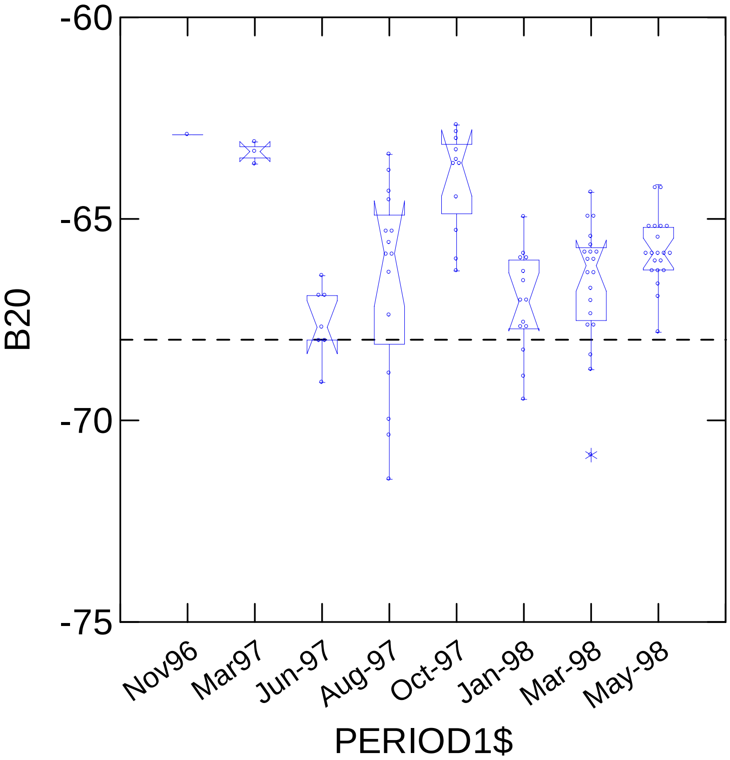


Figure 7. Box-plot of length-normalised hourly mean target strength observed in all periods. Presently used constant term, b_{20} = -68 dB is indicated as a straight line.

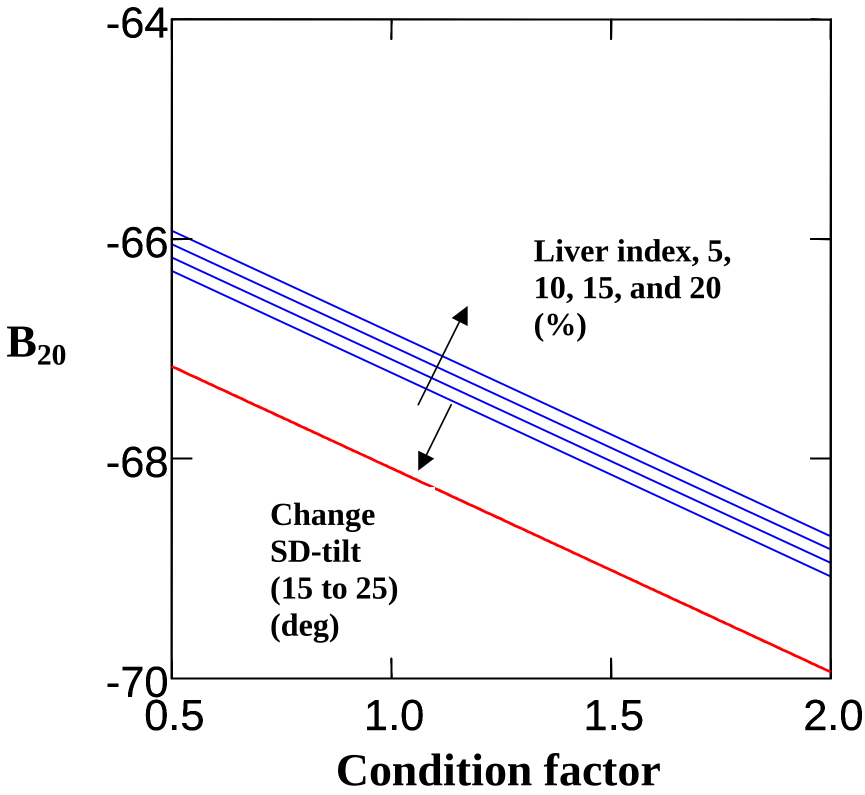


Figure 8. Effect studies of the results from the GLM-analysis for cod. The target strength represented by the constant of the target strength equation, b_{20}, as a function of the fish condition factor. The four blue lines indicate the functional relationship when stepwise changing the liver index from 5 to 20% in steps of 5. The red curve indicate the drop in mean target strength when changing the spread of the tilt angle distribution from 15 degrees to 25 degrees, typical for a simulated day and night situation

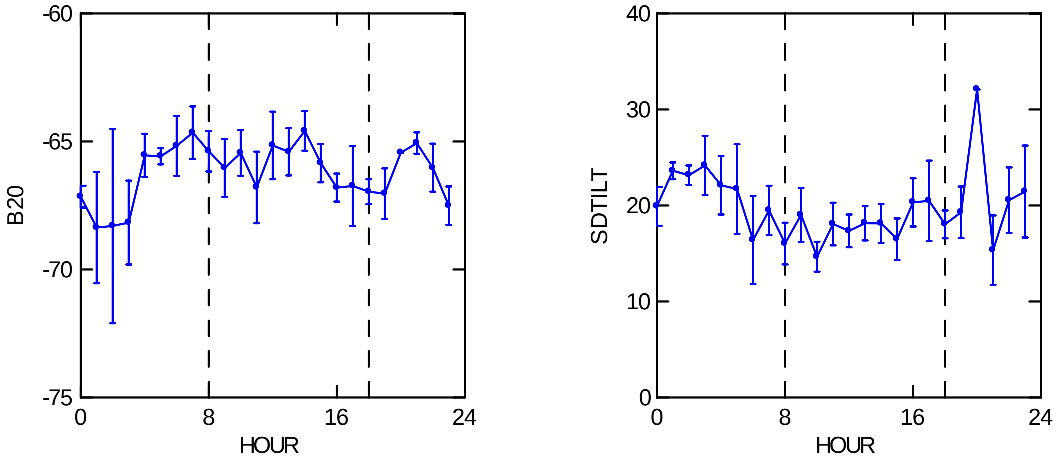


Figure 9. Normalised target strength (a) and standard deviation of the tilt angle distribution, all periods, as a function of observation hour. Day – night borders indicated, with day from 08 – 18. (At this stage, not corrected for day-length or light level in the different periods)