TARGET STRENGTH MEASUREMENTS AND ACOUSTIC BIOMASS ESTIMATION OF CAPELIN AND O-GROUP FISH

by

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INTRODUCTION

Echo integration is now widely used to obtain estimates of abundance of fish populations (THORNE et al. 1971, JOHANNESSON and LOSSE 1973, MØTTUN and NAKKEN 1973 among others). Earlier estimates have mostly been worked out under the assumption that the scattering cross section of the fish is proportional to its weight (URICK 1967). This assumption introduces a bias which is dependent on the size distribution of the fish (NAKEN 1975). However, this is overcome if one introduces a length dependent scattering cross section (BUZETA and NAKKEN 1975, NAKKEN and DOMMASNES 1975).

At Institute of Marine Research acoustic biomass estimation of the stock strength of capelin has been carried out in September - October each year since 1971 and in June - July since 1973. The echo integration system applied during these cruises together with the results are given in NAKKEN & DOMMASNES 1975. The last
year this methodology has also been applied to cod (DALEN, HYLEN and SMEDSTAD, in press). Back scattering properties of capelin were not known, and it has hitherto been assumed that the dependency of the density coefficient (C) on fish length for capelin was similar to that of sprat. Back scattering data for sprat are given in NAKKEN and OLSEN (1973).

During late summer and early autumn O-group fish of many species occur pelagically in the Barents Sea. Knowledge of the pre-recruitment stock is essential in attempts to predict and control fisheries, and the advantage of knowing year-class strength for all species in a region before they are subject to finishing is obvious (DRAGESUND 1971). However, this knowledge is in the Barents Sea area so far limited to relative values (abundance indices) for each species each year (ANON. 1975).

The method of obtaining these indices has improved. At present, a method described by HAUG and NAKKEN (1973) is used. Here a certain number of fish of each species in the trawl catch is used to discriminate between areas of scattered and dense concentrations. But information on the contributions to the total biomass from different species can, only to a small extent, be extracted from the abundance indices values.

The aim of the present paper is to give information on the back scattering properties of some pelagic and O-group fish in the Barents Sea, in order to improve the acoustic biomass estimations of the above mentioned categories of fishes.

METHODS

Experimental set-up

The work took place in a sheltered bay at Skogøya, South Varanger in Finnmark.

An anchored ship with a raft alongside the ship constituted the power station, the laboratory and the accommodation facilities (Fig. 1).
The upward looking transducers were mounted in a loaded aluminum frame submerged from the raft in adjustable wires. The fish was kept in an upside down position by a small float attached to the fish belly in the central part of the sound beam by a suspension of thin nylon gut. A hoisting device made it possible to hook the fish to the suspension at the surface and then lower it to the measuring position at 2.5 m depth (Fig. 1).

The aspect angle of the fish could be contiously changed in the pitch plane. The fish was automatically tilted between $-45^\circ$ and $+45^\circ$ to the horizontal. The overall accuracy was found to be $\pm 2^\circ$ with the worst case of deviation to be $\pm 5^\circ$.

The equipment was calibrated three times during the field period by means of a hydrophone. To check the short time variations of the performance, three or four daily calibrations were carried out by measuring the target strength of a rigid steel sphere, 5 cm in diameter, that was lowered into the actual position.

Each fish to be measured was killed by hitting the frontal part of the brain by a sharp tool. When suspending the fish, care was taken to avoid air in gills and stomach. The measurements started immediately after the fish had reached the measuring position if no other fishes were in the close neighbourhood. Wild fish within the sound beam were however often a problem which caused considerable delays in the experiments.

**Instrumentation**

Fig. 2 shows a block diagram of the instrumentation which also listed below.

- Echosounder EK 38 A, SIMRAD A/S
- Echosounder EK 120 A, SIMRAD A/S
- Transducer, 38 kHz, dim. 10 x 10 cm SIMRAD A/S
- Transducer, 120 kHz, dim. 0.5 cm SIMRAD A/S
- Trigger (electronic) Institute of Marine Research
- Tiltangle indicator and control, sensor and motor Institute of Marine Research
**Oscilloscope Dual trace 1217 B**

Hewlett - Packard

**Echo Integrator QM II**

SIMRAD A/S

**Recorder 7702 B**

Hewlett - Packard

**Signal generator Model 116**

Wavetec

**Signal generator PF 1101**

Marconi

**Frequency counter 5306 AM, meter/counter**

Hewlett - Packard

**Electronic voltmeter Model 2606**

Brüel & Kjær

**Hydrophone LC 32**

Atlantic Research

The transmitted pulselengths were 0.6 ms for both sounders. The sounding repetition was approximately 3.4 pulses per second (200 pulses per minute).

**Data processing**

The information recorded on paper consists of signal voltage amplitudes as function of frequency, tiltangle, aspect, species and size.

During the analysis the following parameters were to be read (R) and calculated (C) from each fish, species and aspect.

- **L** (R): Fish length (cm)
- **U** (R): Maximum observed voltage amplitude (V)
- **FV** (R): Interval of tiltangle within which \( TS \geq TS_{\text{max}} - 6 \text{ dB} \) (degrees)
- **TS_{\text{max}}** (C): Maximum observed target strength

Target strength, \( TS \), was calculated from the following equation

\[
TS = 20 \log \frac{U}{U_r} + TS_r \quad (1)
\]

where \( U \) is observed voltage amplitude, \( U_r \) is the observed voltage amplitude from the reference sphere which has the target strength \( TS_r \). \( TS_r \) is - 38.1 dB at ideal conditions which was the value used in (1).
RESULTS

Besides values of the target strength it is of importance to find the dependency between target strength and length of the fish. To establish this we assume a linear relation between target strength and the logarithm of the fish length, that is

\[ TS = m \log L + b \]  

(2)

m and b are determined by linear regression analysis.

It was originally planned to measure target strength of all length groups of capelin. However, due to difficulties in catching and transporting the smaller capelin from the fishing grounds in the Barents Sea south to the measuring site at Varanger, target strength measurements could only be made for length groups 13 cm to 18 cm. This was considered to few data to apply a linear regression, and it was decided to combine these data with previously measured target strength data from other fish of the order Clupeiformes. Pertinent data for following species of Clupeiformes were included.

<table>
<thead>
<tr>
<th>Species</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capelin</td>
<td>(Mallotus villosus) (present measurements)</td>
</tr>
<tr>
<td>Herring</td>
<td>(Clupea harengus) NAKKEN &amp; OLSEN (1973)</td>
</tr>
<tr>
<td>Salmon</td>
<td>(Salmo salar) ROTTINGEN, unpublished</td>
</tr>
<tr>
<td>Sprat</td>
<td>(Sprattus sprattus) NAKKEN &amp; OLSEN (1973)</td>
</tr>
</tbody>
</table>

These data have been combined and plotted in Fig. 3, and results from the linear regression are shown in Table 1.

The observations and the results of the linear regression for cod (Gadus morhua), saithe (Pollachius virens) and sand eel (Ammodytes sp.) are shown in Figs. 4, 5 and 6, and Table 2.

Target strength measurements of 10 specimens of haddock (Gadus aeglefinus) were made. NAKKEN and OLSEN (1973) also measured target strength of haddock (15 specimens) but the measurements were only published as mean values (Table 3, NAKKEN and OLSEN 1973) because they felt the observations to few to make a linear regression. Fig. 7 and Table 2 combine the present measurements of haddock with those of NAKKEN and OLSEN (1973).
Fig. 8 shows the relation between maximum dorsal aspect target strength and mean angle between points of half maximum amplitude (6 dB points) for cod, haddock and saithe.

DISCUSSION

We would like to pay some specific attention to how to reduce the data by linear regression analysis i.e. what regression to use (RICKER 1973). In order to make a decision one should discuss:

1 - what kind of variability and error which are involved in the variates,
2 - what distributions the variates make,
3 - what has the sampling method been and
4 - is the regression used to describe a relationship, or to make predictions, or both.

Most of the variability in target strength-length observations we find to be inherent in the material more than in the process itself of measuring length and measuring and calculating target strength.

The observations are from a non-random sample which forms an open-ended non-normal distribution.

Primarily the regressions are needed to describe a certain relationship, secondarily however, they will be used to predict target strength from length observations.

These statements lead to the conclusion that functional regression (least geometric mean regression) is preferable to predictive regression (least mean square regression). The functional regression represents the line which minimizes the sum of the products of the vertical and horizontal distance of each point from the line. The slope of the line is

\[ v = \pm \sqrt{\frac{\sum v^2}{\sum x^2}} \]
x and y represent the quantities as measured from their means, i.e., $x = X - \bar{X}$ and $y = Y - \bar{Y}$.

NAKKEN (1975) shows that observations of maximum dorsal aspect target strength can be used to obtain reliable ratios of echo intensity between species and length groups.

The dorsal target strength is

$$TS_{\text{max}} = m \log L + b$$  \hspace{1cm} (4)

or applied for the density coefficient (NAKKEN 1975)

$$C = C_{\text{i}} \cdot C_{\text{s}} \cdot \frac{-m}{10}$$  \hspace{1cm} (5)

$C_{\text{i}}$ is an instrument constant and $C_{\text{s}}$ is a constant for a given species.

Unfortunately the data obtained during the present measurements were too few to give length dependency of the density coefficient based on data from capelin only. However, the capelin belongs systematically to the order Clupeiformes, and in general, with the exception of certain deep-sea species (MARSHALL 1960), clupeiform fish have physostomi swim bladders (FAHLEN 1967, 1968), osseous bone tissue, intermuscular bones, comparatively many vertebrae, fins without spines and cycloid scales. Clupeiform fish therefore have common structural components that are acoustically important, and one feels that this justifies treating the acoustic data for several Clupeiformes together. The obtained values of $m$ for a number of species of O-group fish are listed in Table 2. The value for cod shows a decrease in dB/decade compared to that of larger fish measured by NAKKEN and OLSEN (1973), while the value for sable shows a increase in dB/decade.

It is well known (LOVE 1971, SUIBATA 1970) that there is a change in the directional reflection of fish as the fish size, or rather $L/\lambda$ (where $L$ is fish length and $\lambda$ is wave-length), decreases. There will be a reduction in the number of lobes, and consequently an increase of the $\mu$-angle. Fig. 8 shows the relation between maximum dorsal aspect target strength and the angle between the
6 dB points in the directivity pattern for the measured cod and saithe. The relations found by NAKKEN and OLSEN (1973) are also indicated. The angle between the 6 dB points for cod increases with decreasing fish size, (or decreasing L/λ ), for saithe the angle does not seem to exceed 25°. This may be due to different structure and reflecting properties of the swim-bladders of cod versus that of saithe, a phenomenon already indicated by MIDTUN and HOFF (1962) and MIDTUN and NAKKEN (1971). The tilt angle distribution will thus be of greater importance in abundance estimation of 0-group saithe than for 0-group cod.

**Abundance estimation**

When different categories of fish, i.e., size groups and species are mixed and thus simultaneously contribute to the echo, then the integrated echo intensity M can be written

\[ M = M_{11} + M_{12} + \ldots + M_{1n} + M_{21} + M_{22} + \ldots + M_{2n} + \ldots + M_{p1} + \ldots + M_{pn} \]  

(6)

\( M_{11} \) is the contribution to the integrated echo intensity from length group 1 of species 1, \( M_{12} \) is the contribution from length group 2 of species 1 and so on, altogether \( n \) length groups from each of the \( p \) species. We must assume that frequent sampling, usually with a pelagic trawl, shows the true density ratios between different length groups and species. Following NAKKEN and DOMMASNES (1975):

\[ k_{ai} = \frac{\rho_{A_{ai}}}{\sum_{a=1}^{p} \sum_{i=1}^{n} \rho_{A_{ai}}} \]  

(7)

\( k_{ai} \) is the proportion of the length group of species of the total catch, \( (\text{Total } n \text{ length groups from each of } p \text{ species}) \) and \( \rho_{A_{ai}} \) is the density per unit area of that particular category of fish.

Further

\[ K = \frac{1}{\sum_{a=1}^{p} \sum_{i=1}^{n} k_{ai}} \]  

(8)
where \( C_{ai} \) is the density coefficient for length group \( i \) of species \( a \).

The relationship between the fish density and integrated echo intensity is linear below a certain density (THORNE and WOGDEBY 1970, MIDTTUN and NAKKEN 1973, ROTTINGEN in press.). This leads to:

\[
\rho_{ai} = k_{ai} \cdot \frac{M}{\sum_{a=1}^{p} \sum_{i=1}^{n} \frac{k_{ai}}{C_{ai}}}
\]  \hspace{1cm} (3)

By applying this method absolute fish density can be calculated for the different species where the density coefficients are known (eq. 5, Table 1 and 2).
Table 1. Functional regression \( TS_{\text{max}} = m \log_{10} L + b \) for Clupeiformes for frequencies 38 kHz and 120 kHz m) calculated slope, b) constant of regression, r) correlation coefficient, N) number of fish measured.

<table>
<thead>
<tr>
<th>Frequency kHz</th>
<th>N</th>
<th>m</th>
<th>b</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>103</td>
<td>19.1</td>
<td>64.0</td>
<td>0.89</td>
</tr>
<tr>
<td>120</td>
<td>83</td>
<td>18.4</td>
<td>62.7</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Table 2. Calculated slope (m) and constant (b) of regression lines, \( TS = m \log_{10} L + b \), the correlation coefficient (r) and the number of fish measured (N).

<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency kHz</th>
<th>N</th>
<th>m</th>
<th>b</th>
<th>r</th>
<th>Length range measured (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod</td>
<td>38</td>
<td>32</td>
<td>21.9</td>
<td>63.5</td>
<td>0.81</td>
<td>4.7 - 20.5</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>7</td>
<td>39.4</td>
<td>87.1</td>
<td>0.90</td>
<td>9.0 - 16.5</td>
</tr>
<tr>
<td>Saithe</td>
<td>38</td>
<td>25</td>
<td>37.1</td>
<td>78.0</td>
<td>0.94</td>
<td>7.1 - 14.5</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>11</td>
<td>34.8</td>
<td>78.6</td>
<td>0.84</td>
<td>7.1 - 14.5</td>
</tr>
<tr>
<td>Haddock</td>
<td>38</td>
<td>24</td>
<td>18.7</td>
<td>59.4</td>
<td>0.95</td>
<td>7.2 - 48.0</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>20</td>
<td>28.9</td>
<td>74.0</td>
<td>0.97</td>
<td>7.6 - 48.0</td>
</tr>
<tr>
<td>Sand eel</td>
<td>38</td>
<td>22</td>
<td>45.5</td>
<td>97.1</td>
<td>0.60</td>
<td>9.2 - 18.5</td>
</tr>
</tbody>
</table>
REFERENCES


Fig. 1. Experimental set-up vessel, raft, framemounted transducers and suspension arrangement.
Fig. 2. Composition of instruments.
Fig. 3. Maximum dorsal target strength versus length of Clupeiformes. 1) Herring, 2) Salmon, 3) Sprat and 4) Capelin. Observed values and regression line.
Figure 7. Maximum dorsal target strength versus length of haddock. Observed values and regression line.
Fig. 8. Corresponding values of maximum dorsal target at 38 kHz strength and angel between point of half maximum amplitude (6 db points). 1) cod, 2) saith, 3) and 4) cod and saithe (NAKKEN and OLSEN 1973).