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# ON ACOUSTIC IDENTIFICATION, SIZING AND ABUNDANCE ESTIMATION OF FISH

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## ABSTRACT

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A method using the fish angle (i.e. the change in target strength with fish aspect) for identification purposes is described. Significant differences in fish angle between cod and coalfish have been observed at sea. The effect of fish angle on the sampling volume of an echosounder is discussed, and it is shown that the sampling volume decreases with decreasing fish angle. A method for abundance estimation applying an echo integrator is described and discussed.

## INTRODUCTION

When fish targets are recorded with an echo sounder, three main questions arise:

What kind of fish is it?

What is the size of the fish?

What is the fish density, i.e. number of fish per unit volume water or per unit area?

Fish recordings have so far been idenfified by capture or underwater photography (PARRISH and CRAIG 1969) and also, to some extent, by recognition of typical traces on the recording paper. While the two first methods are time consuming, the third depends on the experience and skill of the observer, and there are no general rules which can be applied for an acoustic identification.

Information on the size of the recorded fish can be obtained from knowledge of target strenght which may be found by an analysis of the received echo signals (CUSHING 1968, CRAIG and FORBES 1969).

The problem concerning the fish density can be regarded as consisting of two parts. Firstly, there is the question of counting or measuring the numbers of fish detected, and secondly, that of finding the sampling volume.

The present paper aims at a technique of direct acoustic identification and sizing of the recorded fish. Further it describes a method for abundance estimation by the application of an echo integrator.

## IDENTIFICATION AND SIZING

### *THE DETECTION SECTOR ANGLE, $\varphi$*

When the sounding ship passes over an individual target, the sector angle, $\varphi$, within which the target is detected, can be determined by the number of echoes received from it during successive transmissions (Fig. 1).

$$\varphi = 2\ arctg\ \frac{v\ (n+1)}{2\ D \cdot p} \tag{1}$$

$v$ is the speed of the ship in cm/sec., $n$ is the number of echoes received from the target, $D$ is the depth of the target in cm and $p$ is the repetition rate of the sounder in number of transmissions per sec.

If the target is a sphere and is passed through a circular beam a number of times at different distances from the acoustic axis, the frequency distribution of $\varphi$ will be as shown in Fig. 4 D. The maximum value of $\varphi$, ($\varphi_{max}$), occurs when the target passes through the beam center. The value of $\varphi_{max}$ depends on the directivity of the transducer and the target strength.

Fish targets however, do not reflect sound as does a sphere. The target strength of a fish varies with its orientation relative to the acoustic axis (MIDTTUN and HOFF 1962, HASLETT 1962 and 1965, LOVE 1969). The dorsal-lateral aspect target strength may be as much as 20 db higher than the head-tail aspect target strength. Therefore the target strength of an «ideal» fish can schematically be presented in a three-dimensional diagram as shown in Fig. 2.

Below, an attempt has been made to determine the frequency distribution of the detection sector angle $\varphi$ when the «ideal» fish passes through a circular beam with different horizontal orientations and at different distances from the acoustic axis. The maximum target strength of the fish is assumed to be equal to that of the above mentioned sphere.

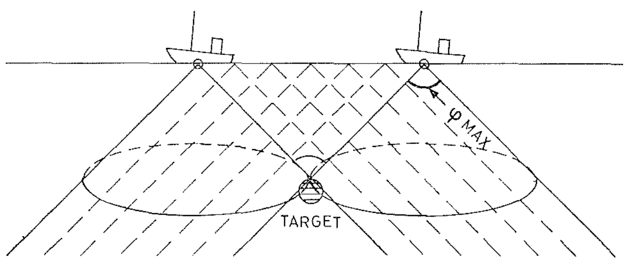


Fig. 1. Schematic picture of a transducer passing a target.

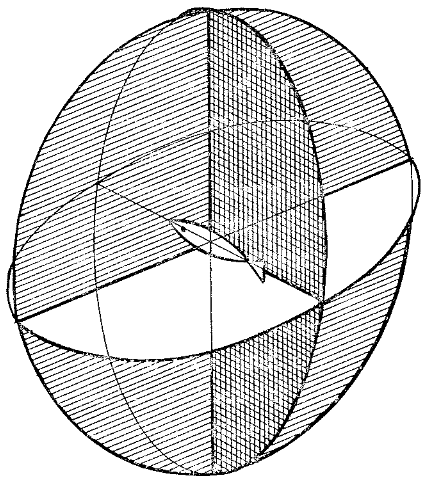

Fig. 2. Target strength pattern for an «ideal» fish target.

The maximum angle, $\varphi_{max}$, will occur when the fish passes through the center of the beam and is orientated with its long axis at a right angle to the course line. Then $\varphi_{max}$ is equal to that of the sphere above.

The angle $\varphi$ of a fish passing through the beam center with its long axis parallel to the course line will be smaller due to the rapid decrease in target strength (Fig. 2). This value of $\varphi$ is called the fish angle, $\varphi_f$.

Thus, the area within which the vertically «looking» circular transducer can «see» the «ideal» fish, is formed approximately as an ellipse (Fig. 3), of which the axes are given by

$$a = 2\ D\ tg\ \frac{\varphi_{max}}{2} \quad \text{and} \quad b = 2\ D\ tg\ \frac{\varphi_f}{2} \tag{2}$$

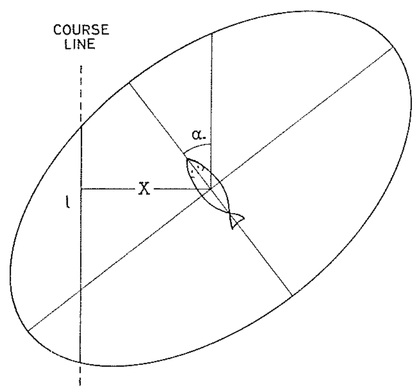


Fig. 3. Schematic presentation of the detection area of an «ideal» fish.

The detection sector angle $\varphi$ can be written

$$l = 2\, D\, tg \frac{\varphi}{2} \tag{3}$$

where $l$ is the length of an arbitrarily chord of the ellipse. In order to eliminate the depth $D$, $l$ is expressed in parts of the long axis, $a$.

$$\frac{l}{a} = \frac{tg \dfrac{\varphi}{2}}{tg \dfrac{\varphi_{max}}{2}} \tag{4}$$

For practical applications (2) and (4) can be written

$$\frac{b}{a} = \frac{\varphi_f}{\varphi_{max}} \text{ and } \frac{l}{a} = \frac{\varphi}{\varphi_{max}} \tag{5}$$

The frequency distribution of $\varphi$ can be expressed in terms of $\varphi / \varphi_{max}$ or $l/a$. $l$ is a function of $\alpha$ and $X$, where $\alpha$ is the angle between the long axis of the fish and the course line, and $X$ is the horizontal component of the distance from the course line to the fish (Fig. 3). If the transducer is considered origin and the course line the $y$ — *axis*, the following equation for the ellipse is obtained:

$$\frac{((x-X) \cos \alpha - y \sin \alpha)^2}{a^2} + \frac{(y \cos \alpha + (x-X) \sin \alpha)^2}{b^2} = 1$$

and

$$l = y_1 - y_2 \text{ for } x = 0 \tag{6}$$

This gives

$$\frac{l}{a} = \frac{\left(1 + \left(\dfrac{b^2}{a^2} - 1\right) \sin^2 \alpha - \dfrac{X^2}{a^2}\right)^{1/2}}{\dfrac{a}{b} \cos^2 \alpha + \dfrac{b}{a} \sin^2 \alpha} \tag{7}$$

Table 1. $l/a$ as a function of $\frac{X}{a}$ and $\alpha$ for $b/a = 1/8$, $b/a = 1/4$ and $b/a = 1/2$.

$$\frac{b}{a} = \frac{1}{8}$$

| $\alpha$ | $\frac{X}{a}$ 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|
| 0....... | 0.124 | 0.122 | 0.119 | 0.115 | 0.108 | 0.100 | 0.089 | 0.075 | 0.054 |
| 10....... | 0.126 | 0.124 | 0.121 | 0.116 | 0.109 | 0.101 | 0.089 | 0.074 | 0.052 |
| 20....... | 0.132 | 0.130 | 0.126 | 0.120 | 0.113 | 0.102 | 0.089 | 0.070 | 0.039 |
| 30....... | 0.143 | 0.140 | 0.135 | 0.128 | 0.118 | 0.104 | 0.085 | 0.056 | |
| 40....... | 0.161 | 0.157 | 0.149 | 0.139 | 0.123 | 0.102 | 0.068 | | |
| 50....... | 0.190 | 0.183 | 0.171 | 0.152 | 0.123 | 0.074 | | | |
| 60....... | 0.240 | 0.225 | 0.198 | 0.152 | 0.052 | | | | |
| 70....... | 0.332 | 0.288 | 0.193 | | | | | | |
| 80....... | 0.518 | 0.201 | | | | | | | |
| 90....... | 0.600 | | | | | | | | |

$$\frac{b}{a} = \frac{1}{4}$$

| $\alpha$ | $\frac{X}{a}$ 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|
| 0....... | 0.249 | 0.245 | 0.238 | 0.229 | 0.217 | 0.200 | 0.179 | 0.150 | 0.109 |
| 10....... | 0.252 | 0.248 | 0.242 | 0.232 | 0.219 | 0.201 | 0.179 | 0.148 | 0.103 |
| 20....... | 0.263 | 0.259 | 0.251 | 0.240 | 0.225 | 0.204 | 0.178 | 0.140 | 0.080 |
| 30....... | 0.284 | 0.278 | 0.268 | 0.254 | 0.234 | 0.208 | 0.171 | 0.116 | |
| 40....... | 0.317 | 0.309 | 0.295 | 0.275 | 0.246 | 0.205 | 0.143 | | |
| 50....... | 0.369 | 0.356 | 0.333 | 0.299 | 0.248 | 0.167 | | | |
| 60....... | 0.451 | 0.427 | 0.383 | 0.312 | 0.182 | | | | |
| 70....... | 0.585 | 0.528 | 0.416 | 0.160 | | | | | |
| 80....... | 0.783 | 0.621 | 0.076 | | | | | | |
| 90....... | 0.917 | 0.600 | | | | | | | |

$$\frac{b}{a} = \frac{1}{2}$$

| $\alpha$ | $\frac{X}{a}$ 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|
| 0....... | 0.497 | 0.490 | 0.477 | 0.458 | 0.433 | 0.400 | 0.357 | 0.300 | 0.218 |
| 10....... | 0.503 | 0.495 | 0.482 | 0.463 | 0.436 | 0.402 | 0.357 | 0.297 | 0.209 |
| 20....... | 0.521 | 0.512 | 0.497 | 0.475 | 0.446 | 0.407 | 0.356 | 0.286 | 0.175 |
| 30....... | 0.551 | 0.541 | 0.523 | 0.497 | 0.462 | 0.414 | 0.349 | 0.256 | 0.031 |
| 40....... | 0.598 | 0.584 | 0.561 | 0.528 | 0.481 | 0.416 | 0.324 | 0.162 | |
| 50....... | 0.662 | 0.644 | 0.612 | 0.565 | 0.497 | 0.399 | 0.236 | | |
| 60....... | 0.747 | 0.721 | 0.674 | 0.602 | 0.495 | 0.318 | | | |
| 70....... | 0.848 | 0.808 | 0.737 | 0.624 | 0.439 | | | | |
| 80....... | 0.940 | 0.885 | 0.784 | 0.615 | 0.276 | | | | |
| 90....... | 0.980 | 0.917 | 0.800 | 0.600 | 0.000 | | | | |

Table 1 shows $l/a$ as a function of $a$ and $\frac{X}{a}$ for three values of $b/a$. Frequency distributions of $l/a$ are obtained from these tables and shown in Fig. 4. The distributions have marked peaks when $l$ equals $b$ or $\varphi$ equals $\varphi_f$. Consequently, the fish angle, $\varphi_f$, can be found when $\varphi_{max}$ is known. In Table 2 are listed frequency distributions of $\varphi/\varphi_{max}$ for different values of $\varphi_f/\varphi_{max}$.

When all the fish recorded have the same fish angle, $\varphi_f$, and are distributed at random in horizontal orientation and distance from the acoustic axis, the distribution of $\varphi/\varphi_{max}$ will be one of the horizontal distributions of Table 2. If however, there is a variation in fish angle, then the distribution of $\varphi/\varphi_{max}$ can be considered as a sum of horizontal distributions in Table 2. Let $n_1$ be the number of observed $\varphi_1$ values, $n_2$ the number of observed $\varphi_2$ values and so on, and let further $x_1$ be the number of fish with $\varphi_f = \varphi_2$, $x_1$ the number of fish with $\varphi_f = \varphi_1$ and so on, then, the following set of equations is deduced

$$\begin{array}{l} a_{11}\,x_1 + a_{12}x_2 + a_{13}x_3 + \dots\dots\dots + a_{110}\,x_{10} = n_1 \\ a_{21}\,x_1 + a_{22}x_2 + a_{23}x_3 + \dots\dots\dots + a_{210}\,x_{10} = n_2 \\ \quad\vdots \\ a_{101}x_1 + a_{102}x_2 + a_{103}x_3 + \dots\dots\dots + a_{1010}x_{10} = n_{10} \end{array} \tag{8}$$

The coefficient $a_{11}$ to $a_{1010}$ are taken from Table 2, and the frequency distribution of $\varphi_f$ is found.

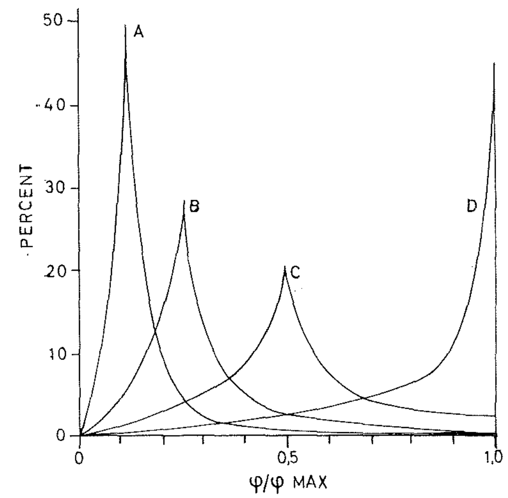


Fig. 4. Distribution in percent of $\varphi/\varphi_{max}$ for $\varphi_f/\varphi_{max}$ equal to *A*) 1/8, B) 1/4, *C*) 1/2 and *D*) 1.

Table 2. Frequency distribution in percent of $\varphi/\varphi_{max}$ for different ratios of $\varphi_f/\varphi_{max}$. The fish is distributed and orientated at random with its long axis horizontally.

| $\varphi_f/\varphi_{max}$ | $\varphi/\varphi_{max}$ 0–0.1 | 0.1–0.2 | 0.2–0.3 | 0.3–0.4 | 0.4–0.5 | 0.5–0.6 | 0.6–0.7 | 0.7–0.8 | 0.8–0.9 | 0.9–1.0 | Detectability in % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0–0.1 | 93 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 63 |
| 0.1–0.2 | 15 | 63 | 13 | 4 | 2 | 1 | 1 | 0 | 0 | 0 | 66 |
| 0.2–0.3 | 5 | 20 | 45 | 15 | 6 | 3 | 3 | 1 | 1 | 1 | 69 |
| 0.3–0.4 | 1 | 9 | 20 | 38 | 13 | 8 | 4 | 3 | 3 | 2 | 71 |
| 0.4–0.5 | 1 | 6 | 9 | 17 | 33 | 14 | 8 | 5 | 4 | 4 | 75 |
| 0.5–0.6 | 1 | 3 | 7 | 11 | 16 | 29 | 14 | 8 | 6 | 5 | 80 |
| 0.6–0.7 | 1 | 2 | 5 | 8 | 9 | 17 | 27 | 15 | 9 | 7 | 85 |
| 0.7–0.8 | 1 | 2 | 4 | 6 | 7 | 10 | 17 | 26 | 16 | 11 | 90 |
| 0.8–0.9 | 1 | 1 | 4 | 5 | 6 | 8 | 11 | 17 | 29 | 18 | 95 |
| 0.9–1.0 | 1 | 1 | 2 | 4 | 5 | 7 | 10 | 14 | 22 | 36 | 100 |

*RESULTS OF OBSERVATIONS*

Observations of $\varphi$ for cod and coalfish are shown in Fig. 5 A. Fig. 5 B presents corresponding distributions of $\varphi_f$ as calculated from equation (8).

The target strength and length distributions from the same observations are presented in Fig. 6. The technique of observation is described by MIDTTUN (1966). The target strengt is calculated by a method similar to that described by CRAIG and FORBES (1969). However, only the maximum signal strength from each fish has been used, and it is assumed that this maximum occured when the fish passed the transverse axis of the beam. During all the observations the zero signal strength corresponded to a target strength of —40db.

In Fig. 7 the results of the analysis are shown in a $\varphi_f$ — TS diagram. The two points are the mean values, and the rectangular areas are limited by the standard deviations of the observations.

Fig. 6 and 7 show that no significant difference was observed between the two species with regard to the target strength. This is not surprising as the lengths were approximately the same. The target strength values appeared to be rather low.

Regarding $\varphi_f$, however, a considerable difference between the two species was observed, and this might in future be used for identification purposes.

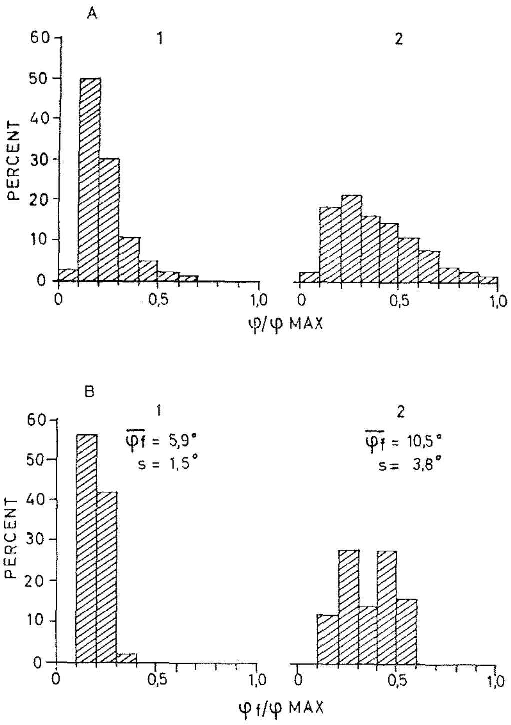


Fig. 5. Distribution in percent of *A*) $\varphi/\varphi_{max}$ and B) $\varphi_f/\varphi_{max}$ for 1) coalfish and 2) cod.

*DISCUSSION*

The observed $\varphi_f$ (Fig. 5) were lower than those calculated from the measurements of Midttun and Hoff (1962). The mean lengths of the fish were, however, larger in the present experiments and therefore smaller fish angles may be expected.

Also the observed mean target strength were low as compared to the maximum values reported by Midttun and Hoff (1962) even though the fish were larger. This difference is probably caused by the fish under observation being more or less inclined from the horizontal. Most underwater pictures show that fishes are usually inclined relative to each other, and consequently they are also inclined relative to the horizontal plane. From this follows that field measurements of target strengths will always be low compared to the maximum values measured in laboratories.

If a mean inclination of 5° to the horizontal plane is introduced to the data of Midttun and Hoff (1962), the target strength of cod will

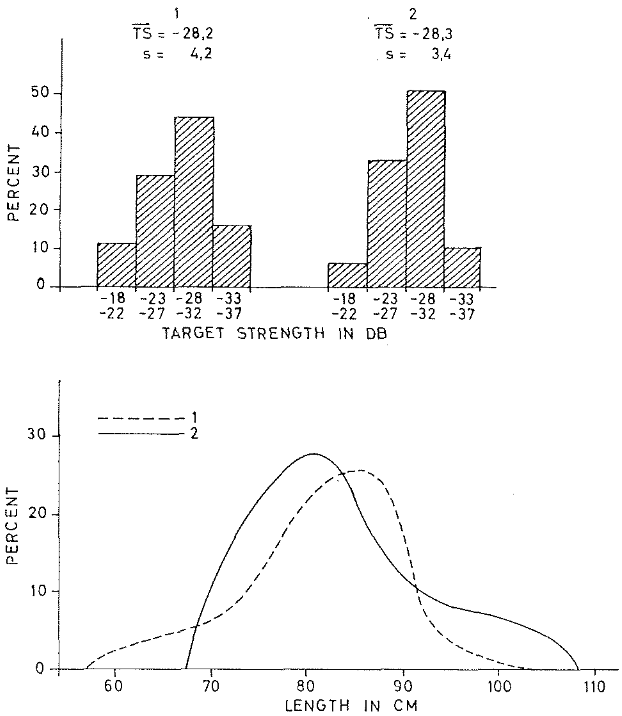


Fig. 6. Distribution in percent of target strength. 1) coalfish and 2) cod. Corresponding length distributions are shown below.

be reduced with a mean value of 5.5 db or, if the maximum dorsal aspect target strength of an 85 cm cod is taken to be — 20db, then the average inclination of the cod in our field observations is between 7 and 10°.

The detection sector angle, and consequently the fish angle as defined by us, will be influenced by the settings of the sounder. The difference obtained between cod and coalfish however, is not influenced by this since all the observations were made with the same sounder at the same settings. Another factor which will alter the detection angle, is the roll and pitch of the vessel (Fig. 4 SUOMALA 1970). As no measurements of pitch and roll angles were carried out, we were not able to analyse its influence on the results.

We assume the fish to be orientated at random but with the long axis in the horizontal plane. The first assumption was probably partly fulfilled by the pattern of different courses used during the observations. The second was, as already mentioned, not fulfilled. Considering the target strength measurements it is, however, not probable that the difference in fish angles between cod and coalfish should be caused by a

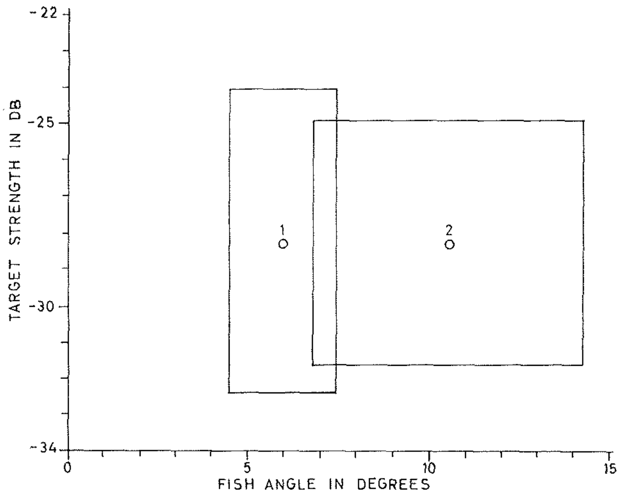

Fig. 7. Fish angle — target strength diagram showing mean values (circles) and standard deviations of observations (straight lines). 1) coalfish and 2) cod.

systematic difference in inclination between the two species during the observations.

The reason for this difference in fish angles is more likely to be found in the size and form of the swimbladders as pointed out by MIDTTUN and HOFF (1962).

More experimental work should be carried out on a number of species and for different fish sizes in order to find out more conclusively whether the fish angle can be of general value as a tool in distinguishing between fish species as it would appears from our results on cod and coalfish. In future observations should be carried out with stabilized transducers in order to eliminate errors caused by the rolling of the ship.

## ABUNDANCE ESTIMATION

### *METHOD*

Methods of abundance estimation are described in PARRISH (1969) and ANON. (1969). In the following the application of an echo integrator for the purpose of measuring fish density is explained.

The integrator was introduced by DRAGESUND and OLSEN (1965) and has recently been modified (BODHOLT 1969). The signal voltage is now squared before integration, and the output of the integrator is therefore proportional to number of fish both when multiple and individual fish targets are recorded.

Following MIDTTUN and NAKKEN (1968) we write

$$M = C_1 \cdot N \tag{9}$$

where $M$ is the reading of the integrator, $N$ is the number of fish giving this reading, and $C_1$ is the mean contribution to $M$ from one fish.

When at constant fish density, $\varrho$ (number per unit volum water) applying a TVG (time varied gain) proportional to the fourth power of the depth, the number of recorded fish will increase proportional to the square of the depth, $D$. For an integration over a given depth interval equation (9) can be written

$$M_D{}^4 = C_2 \cdot \varrho \cdot D^2 \tag{10}$$

where $M_D4$ is the integrator reading when the TVG is set proportional to the fourth power of the depth (40 log D), and $D$ is the mean depth of the observed depth interval.

From (10) we get

$$\frac{M_D{}^4}{D^2} = C_2 \cdot \varrho \tag{11}$$

The expression on the left side is proportional to the integrator reading when the TVG is proportional to the second power of the depth (20 log D). Consequently, when a TVG proportional to the second power of the depth is used, the integrator reading will be proportional to fish density

$$\varrho = C_3 \cdot M_D{}^2 \tag{12}$$

The constant $C_3$ is now independent of depth, but dependent of target strength and $\varphi_f$ and the characteristics of the sounder. If target strength and $\varphi_f$ of the recorded fish are known, $C_3$ can be found. The most convenient way to find $C_3$, however, is to count single fish traces, say 30, on the paper record, calculate $\varrho$, and divide it with the correspon-ding $M_D{}^2$. The obtained value of $C_3$ can be used in equation (12) as long as the fish species and size remain unchanged.

## *DISCUSSION*

It is important to determine if equation (12) is also valid for schools of fish. In other words, will one fish contribute to the integrator reading with the same value when member of a school as it does when recorded as an individual?

The sampling volume will increase with increasing school density which means that $C_3$ should be larger for fish as school members compared to single fish. The increment in $C_3$, however, will be small, and we consider it negligible.

In order to determine $C_3$, the sampling volume must be known. This can be found from the distribution of maximum target strength of the fish and from the directivity pattern of the transducer. Due to the directivity of fish this procedure will give too low estimates of fish density as seen from Table 2. A transducer at the surface cannot detect fish with large values of $\alpha$ and $X$ within the estimated angle, $\varphi_{max}$. The detectability decreases with decreasing $\varphi_f$. Probably, the fish is also inclined relative to the horizontal, and then the detectability in Table 2 will be further reduced. Therefore, for wide beam transducers the sampling volume should be calculated from the observed values of $\varphi$ instead of from the directivity diagram of the transducer.

Equation (12) is not valid for large fish densities. From echo records we know that below dense fish schools the strength of the bottom echo is considerably reduced due to attenuation of sound within the school. In such cases values of $\varrho$ calculated from equation (12) will be too low. However, at the front of the reflected signal from a school the attenuation might be neglected, and during the raise time of the echo the squared voltage should be proportional to the number of reflectors within one half pulsevolume. This then makes it possible to find the fish density in the uppermost part of the school.

The response of fish to the ship noise might cause a lower fish density within the field sampled with an echosounder. Olsen (1969) showed that a typical response of herring to an acoustic stimulus was to turn away from the sound source and swim towards the area of less sound intensity. It is not known, however, whether the fish will react in this way to the noise of a ship.

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