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ON ACOUSTIC IDENTIFICATION, SIZING AND ABUNDANCE ESTIMATION OF FISH

by

L. Midttun and Odd Nakken[x)]

1. INTRODUCTION.

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

1. What kind of fish is it ?
2. What is the size of the fish ?
3. What is the fish density, i.e. number of fish per unit volume or per unit area ?

One of the main problems in acoustic fish recordings is related to the fist question. So far identification has been done by capture or underwater photographying (Parrish and Craig 1969) and also to some extent by recognition of traces on the recording paper. While the two first methods are difficult and often time consuming, the third depends on the experience and skill of the observer, and there are no general rules which have been applied for an acoustic identification.

Information on the size of the recorded fish can be obtained from knowledge of target strength which may be found by an analyzis of the received echo signals (Cushing 1968, Craig and Forbes 1969).

The third 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 direct acoustic identification and sizing of the recorded fish. It further describes a method for abundance estimation by the application of an echo integrator.

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2. IDENTIFICATION AND SIZING.

The detection sector angle, .

When the sounding ship passes over an individual target, the sector angle, φ , within which the target is detectable, can be determined by counting the number of echoes received from it during sucessive transmissions (Fig. 1).

$$\varphi = 2 \text{ arctg } \frac{v(n+1)}{2 D.p} \qquad (1)$$

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.
p is the repetition rate of the sounder in pings/sec.

If the target is a sphere with a spherical reflectivity pattern and passes through a circular beam a number of times at different distances from the acoustic axis, the frequency distribution of φ will be as shown in Fig. 3 D. The maximum value of φ (φ max) occurs when the target passes through the beam center. The value of φ 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 fish varies with their 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. Schematically the target strength of an "ideal" fish can be represented as a three-dimensional polar diagram as shown in Fig. 2.

We shall now try to find the frequency distribution of the detection sector angle φ when the "ideal" fish passes through our circular beam with different horizontal orientations and at different distances from the acoustic axis. We assume the maximum target strength of our fish to be equal to that of the above mentioned sphere.

The maximum angle, φ 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 φ max is the same as for the sphere above.

The angle φ of a fish passing through the beam center with its long axis parallel to the course line will be smaller due to the variation in target strength (Fig. 2). This value of φ is called the fish angle, φ_f .

Thus, the area within which the vertical "looking" circular transducer can "see" the "ideal" fish is formed approximately as an ellipse (Fig. 4), which axis are given by

$$a = 2\ D\ tg\ \frac{\varphi_{max}}{2} \quad , \qquad b = 2\ D\ tg\ \frac{\varphi_f}{2} \qquad (2)$$

The detection sector angle φ is given by

$$\ell = 2\ D\ tg\ \frac{\varphi}{2} \qquad (3)$$

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

$$\frac{\ell}{a} = \frac{tg\ \frac{\varphi}{2}}{tg\ \frac{\varphi_{max}}{2}} \qquad (4)$$

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

$$\frac{\ell}{a} = \frac{\varphi}{\varphi_{max}} \quad \text{and} \quad \frac{b}{a} = \frac{\varphi_f}{\varphi_{max}} \qquad (5)$$

The frequency distribution of φ can be expressed in terms of φ / φ max or ℓ/a. ℓ is a function of α and X , where α 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. 4). If the transducer is considered as origo and the course line as the y - axis, we will get the following equation for the ellipse

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

$$\text{and } \ell = y_1 - y_2 \quad \text{for } x = 0 \qquad (6)$$

This gives

$$\ell/a = \frac{\sqrt{1 + \left(\frac{b^2}{a^2} - 1\right)\sin^2\alpha - \frac{x^2}{a^2}}}{\frac{a}{b}\cos^2\alpha + \frac{b}{a}\sin^2\alpha} \qquad (7)$$

Table 1 shows ℓ/a as a function of α and $\frac{x}{a}$ for three values of b/a. Frequency distributions of ℓ/a is obtained from these tables and shown in Fig. 3. The distribution have marked peaks when ℓ equals b or φ equals φ_f. Consequently the fish angle, φ_f, can be found when φ max is known. In Table 2 are listed frequency distributions of φ/φ max for different values of φ_f/φ max.

When all the fish recorded have the same fish angle, φ_f, and are distributed at random in horizontal orientation and distance from the acoustic axis, the distribution of φ/φ max will be one of the horizontal distributions of Table 2. If however, there is a variation in fish angle, then the distribution of φ/φ max can be considered as be a sum of distributions in Table 2. Let n_1 be the number of observed φ_1 values, n_2 the number of observed φ_2 values and so on, and let further x_1 be the number of fish with $\varphi_f = \varphi_1$, x_2 the number of fish with $\varphi_f = \varphi_2$ and so on, then, the following set of equations is deduced

$$\begin{array}{ccccccccc}
a_{11} x_1 & + & a_{12}x_2 & + & a_{13} x_3 & + \cdots\cdots\cdots + & a_{110} x_{10} & = & n_1 \\
2_{21} x_1 & + & a_{22}x_2 & + & a_{23} x_3 & + \cdots\cdots\cdots + & a_{210} x_{10} & = & n_2 \\
\cdot & & \cdot & & \cdot & & \cdot & & \cdot \\
\cdot & & \cdot & & \cdot & & \cdot & & \cdot \\
\cdot & & \cdot & & \cdot & & \cdot & & \cdot \\
a_{101}x_1 & + & a_{102}x_2 & + & a_{103}x_3 & + \cdots\cdots\cdots + & a_{1010}x_{10} & = & n_{10}
\end{array} \qquad (8)$$

The coefficients a_{11} to a_{1010} are taken from Table 2, and the frequency distribution of φ_f is found.

Results of observations.

Observations of φ for cod and coalfish are shown in Fig. 5 A. The corresponding distributions of φ_f as calculated from equation (8) are presented below (Fig. 5 B).

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 strength is calculated by a method similar to that described by Craig and Forbes (1969). However, we have only used the maximum signal strength from each fish, 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 -40 db.

In Fig. 7 the results of the analysis are shown in a φ_f - TS diagram The two points are the mean values, and the rectangular areas are limited by the standard deviations.

As seen from Figs. 6 and 7, no significant difference was observed, for the two species with regard to the target strength. This is not surprising as the lengths were practically the same. The values of TS appeared to be rather low.

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

<u>Discussion.</u>

The observed values of φ_f (Fig. 5) were lower than those found 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 values of target strengths were low as compared to the values reported by Midttun and Hoff, even though the fish were larger. This difference is probably caused by the fish having an inclination from the horizontal. Most underwater pictures show that fishes are usually more or less 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 in Fig. 4 of Midttun and Hoff (1962) we let the fish have a mean inclination of 5° to the horizontal plane, then the target strength of cod will be reduced with a mean value of 5.5 db. Or if we take the maximum dorsal aspect target strength of an 85 cm cod to be - 20 db, then the average inclination of the cod in our field observations is approximately 7-10°.

The detection sector angle and consequently the fish angles as defined by us will be influenced by the settings of the sounder. The difference obtained between cod and coalfish in this work is however, 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 (Suomala 1970 Fig. 4). As no measurements of pith/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 were 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 probably that the difference in fish angles between cod and coalfish should be caused by a 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).

In the authors opinion 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 could appear from our results on cod and coalfish.

Observations should be carried out with stabilized transducers in order to eliminate errors caused by the rolling of the ship.

3. ABUNDANCE ESTIMATION

Method.

Methods of abundance estimation are described in the FAO Fisheries Technical Paper No. 83[x)] and FAO Fisheries Report No. 78 (Parrish 1969). In the following we shall explain the application of an echo integrator for the purpose of measuring fish density.

x) (Anon., 1969)

The integrator we use was introduced by Dragesund and Olsen (1965) and has recently been modified by Simonsen og Mustad A/S (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.

At a constant fish density, ρ(number per unit volum) applying a TVG proportional to the fourth power of the depth, the number of recorded fish will increase proportional to the square of the depth, D. For a given integration interval equation (9) can then be written

$$M_D4 = C_2 \cdot \rho \cdot D^2 \tag{10}$$

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

$$\frac{M_D4}{D^2} = C_2 \cdot \rho \tag{11}$$

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 proportinal to fish density.

$$\rho = C_3 \cdot M_D2 \tag{12}$$

The constant C_3 is now independent of depth, but dependent of TS and φ_f and the characteristics of the sounder. If TS and φ_f

of the recorded fish is 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 ρ , and divide it with the corresponding M_D2 . The obtained value of C_3 can be used in equation (12) as long as the fish specie and size remains unchanged.

Discussion.

Is equation (12) also valid for schools of fish ? In other words will one fish when member of a school contribute to the integrator voltage with the same value 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 the present authors 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 estimate of fish density, as seen from table 2. A transducer at the surface cannot detect fish with high values of α and X within the estimated angle φ max. The detectability decreases with decreasing φ_{3} . If we allow the fish to be inclined relative to the horizontal, 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 φ instead of from the directivity diagram of the transducer.

Equation (12) is not valid for large fish densities. From echograms 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 ρ 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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Table 1.

ℓ/a as a function of $\frac{x}{a}$ and α for
A: b/a = 1/8, B: b/a = 1/4 and C: b/a = 1/2.

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								

B.

	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							

C.

	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 2.

Frequency distribution in per cents of φ / φ max. for different relations of φ_f / φ max. The fish is distributed and orientated at random with its long axis in the horizontal plane.

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

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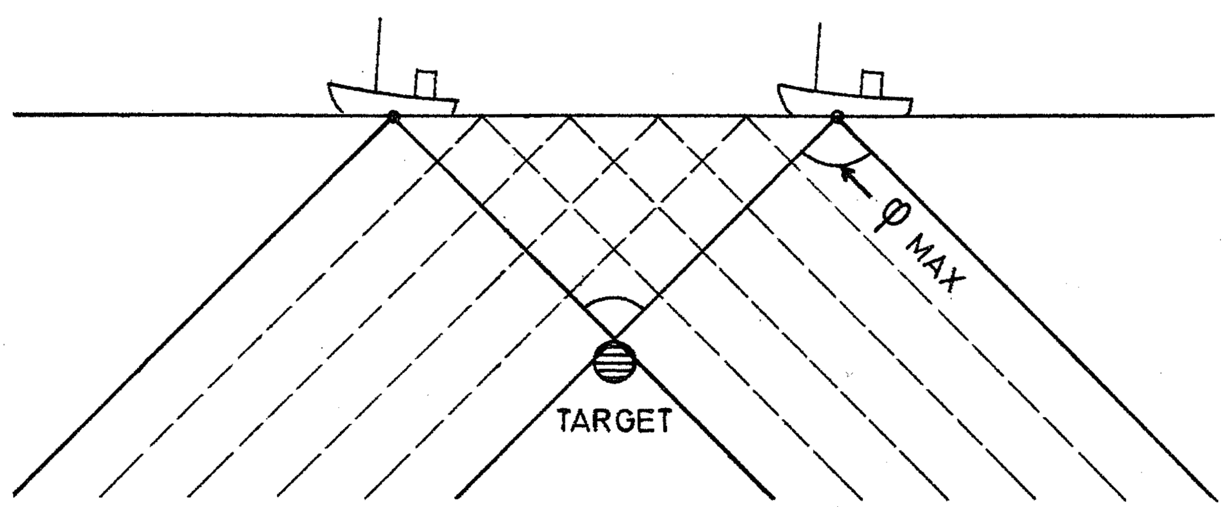

Fig. 1. Schematic picture of a transducer passage of a target.

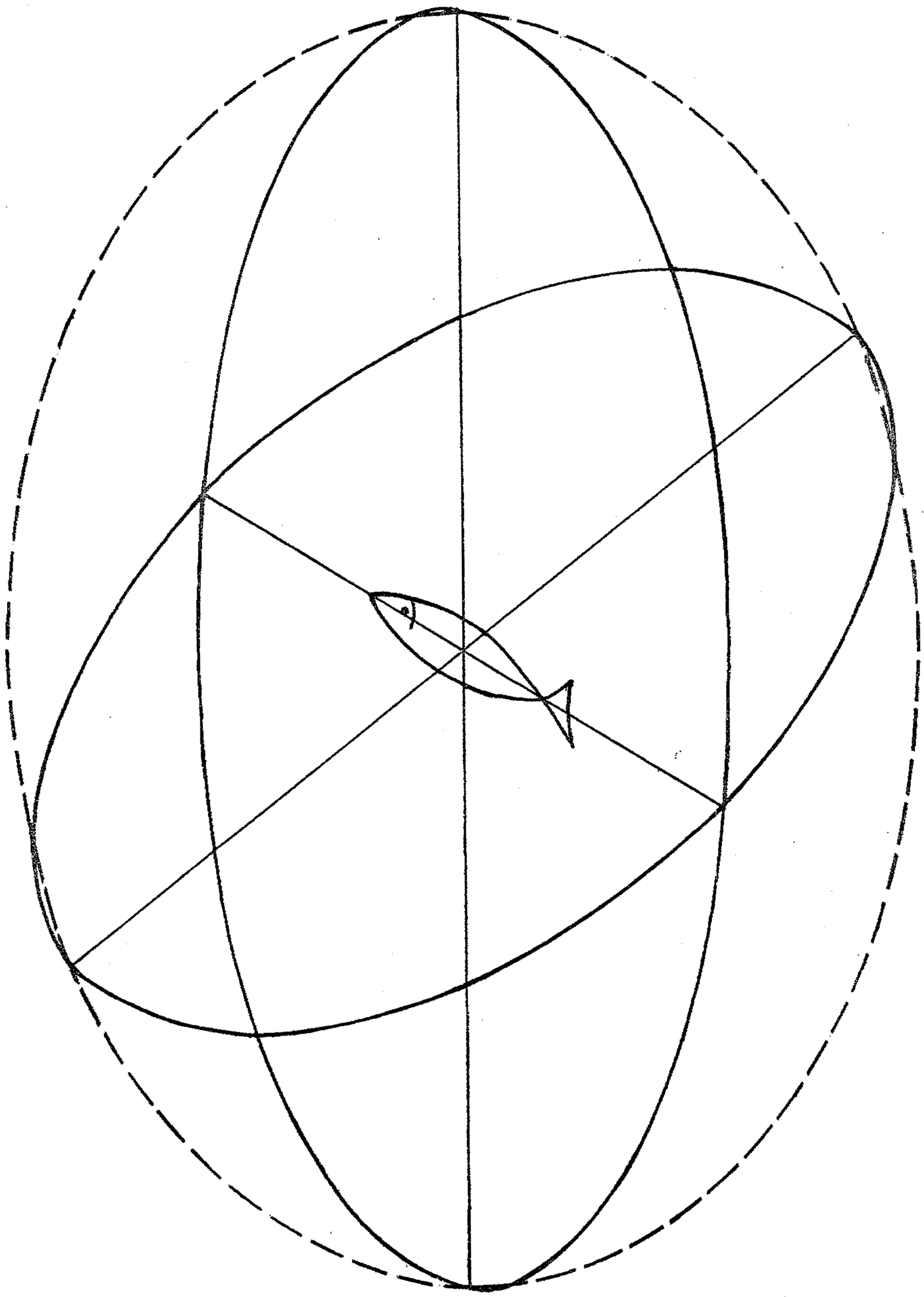

Fig. 2. Schematic picture of the reflectivity pattern of an "ideal" fish target.

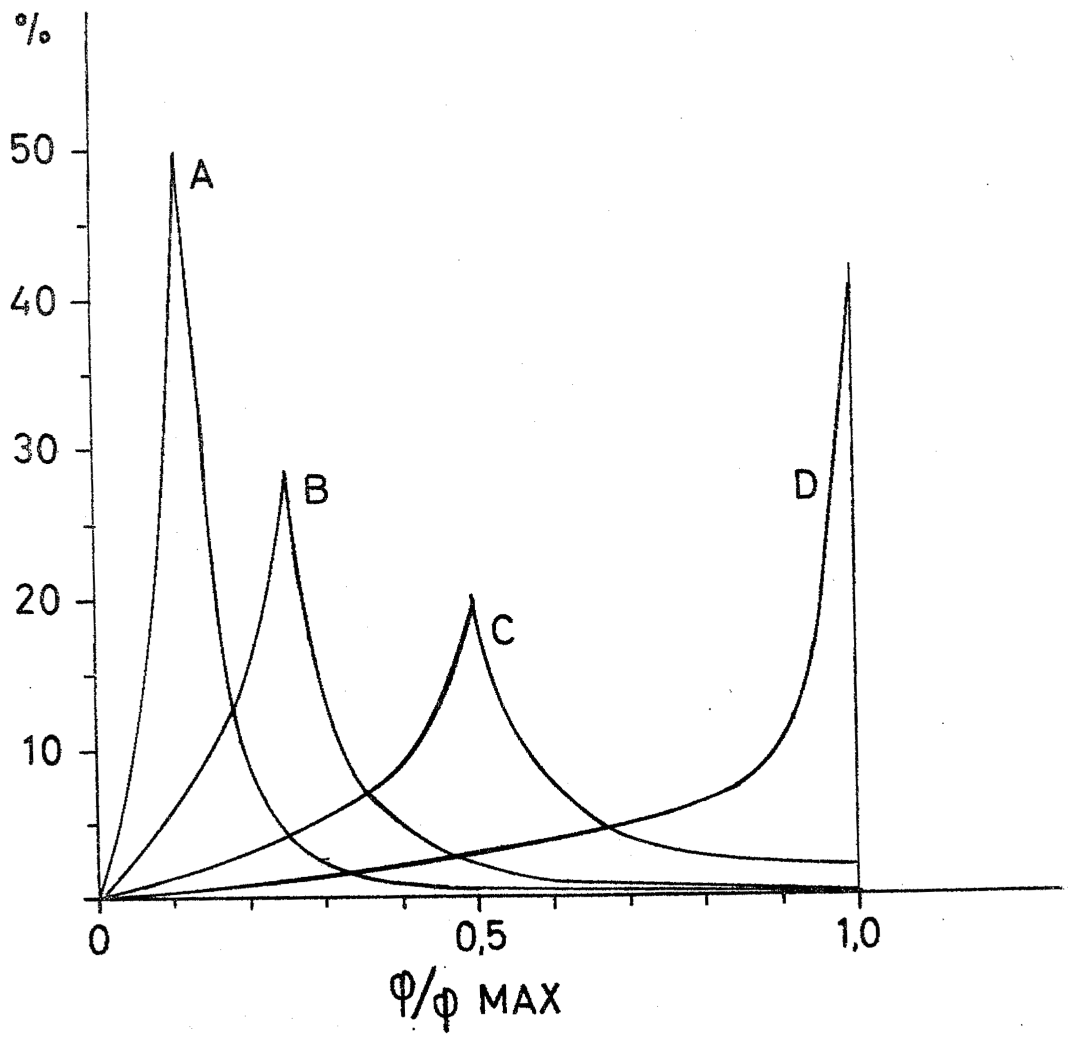

Fig. 3. Distribution in per cent of φ / φ max for φ_f / φ max equal to A: 1/8, B: 1/4, C: 1/2 and D: 1.

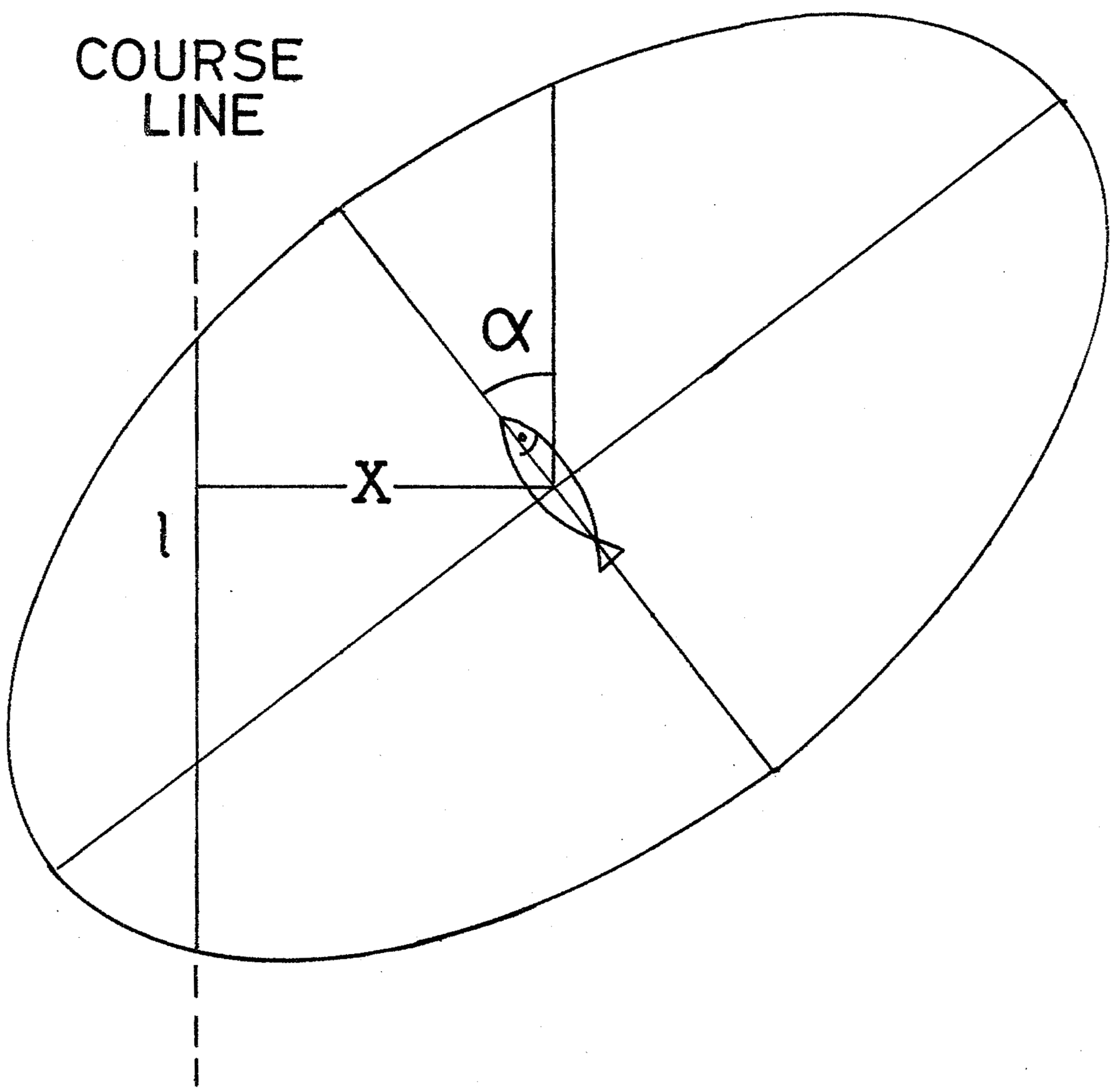

Fig. 4. Schematic presentation of the detection area of an ideal fish.

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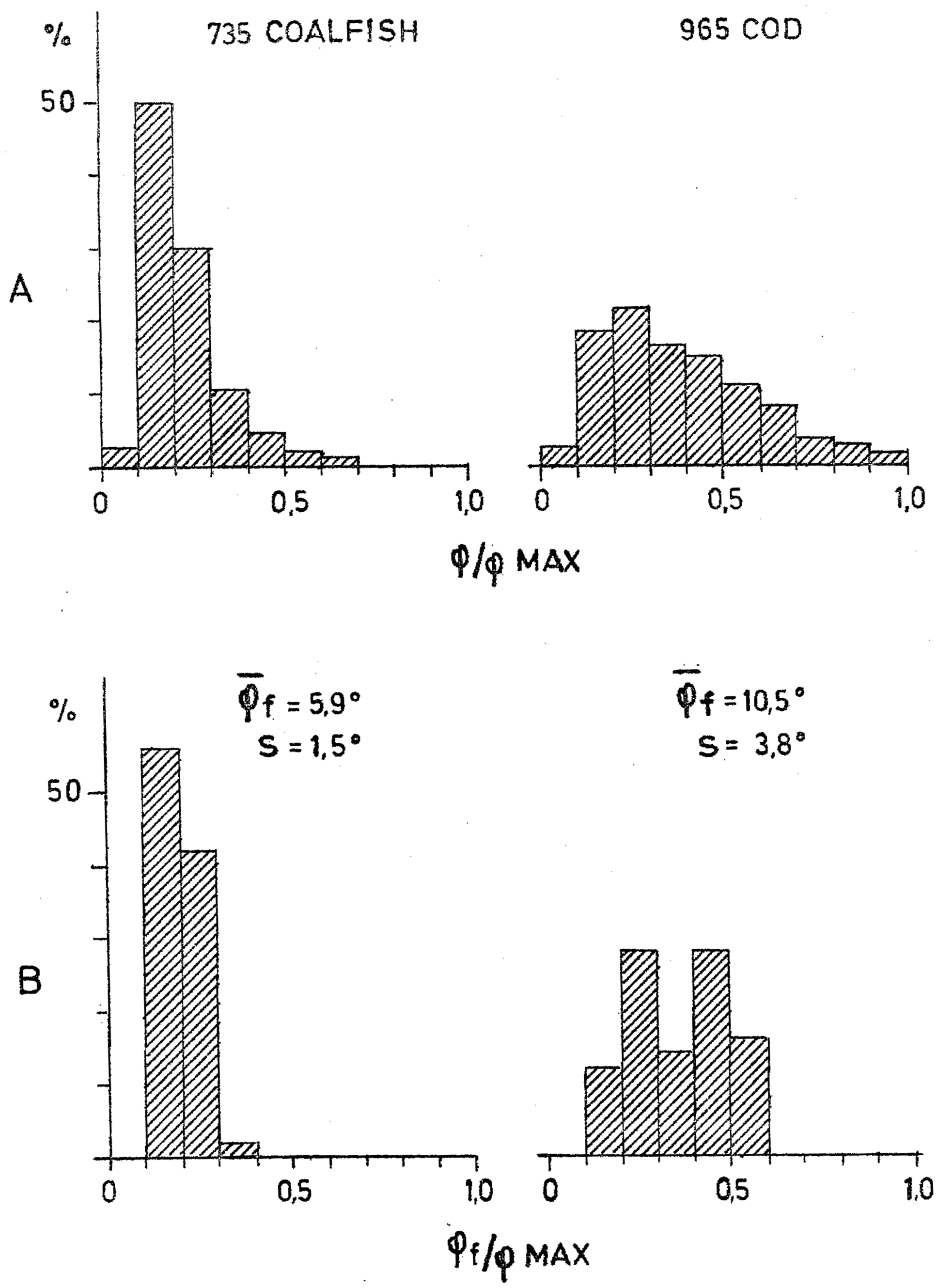

Fig. 5. A: Distribution in per cent of observed values of φ/φ_{max} from coalfish and cod.
B: Distribution in per cent of the corresponding fish angle values, φ_f/φ max.

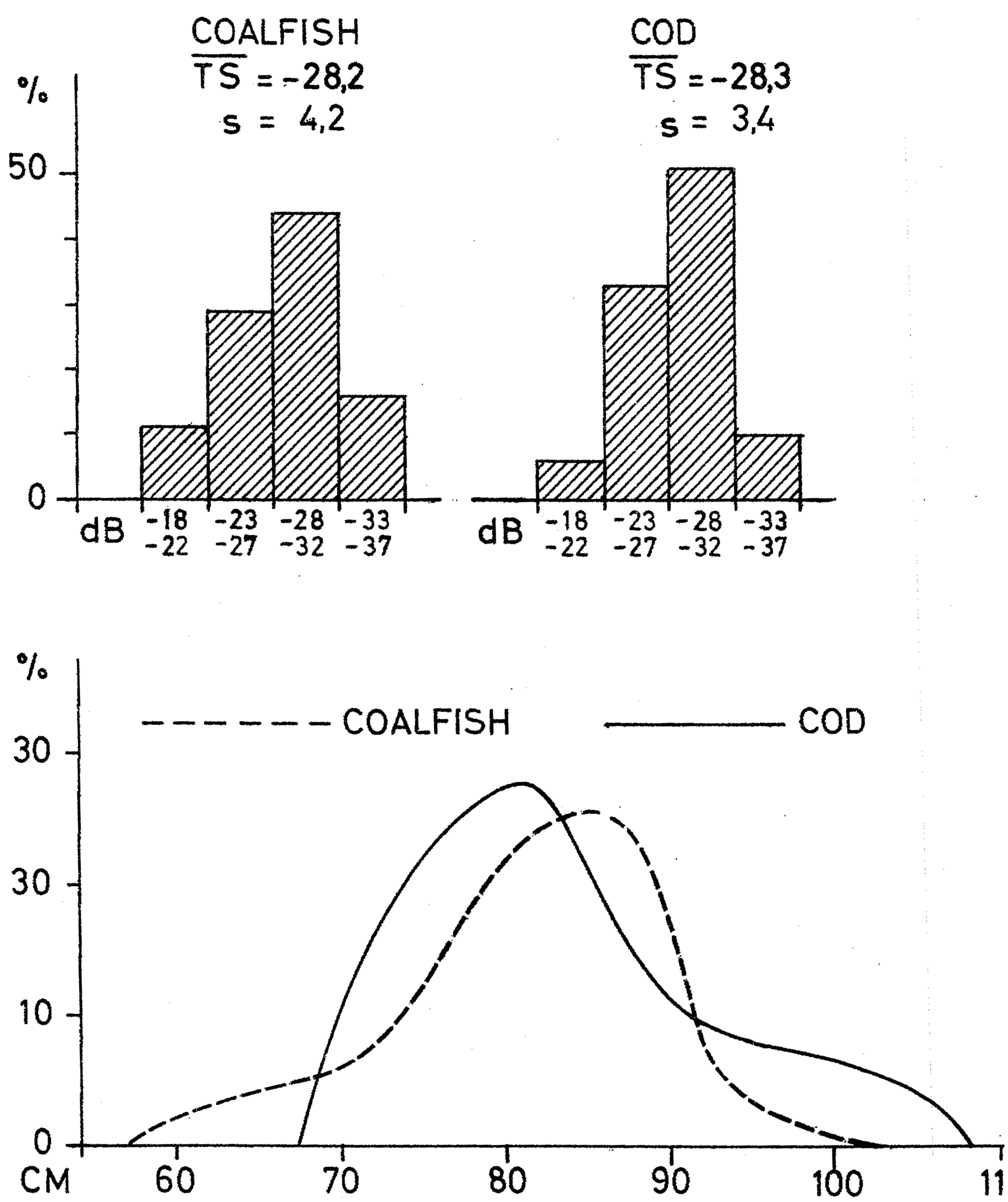

Fig. 6. Distribution in per cent of target strength, TS, for observed coalfish and cod, with corresponding length distribution below.

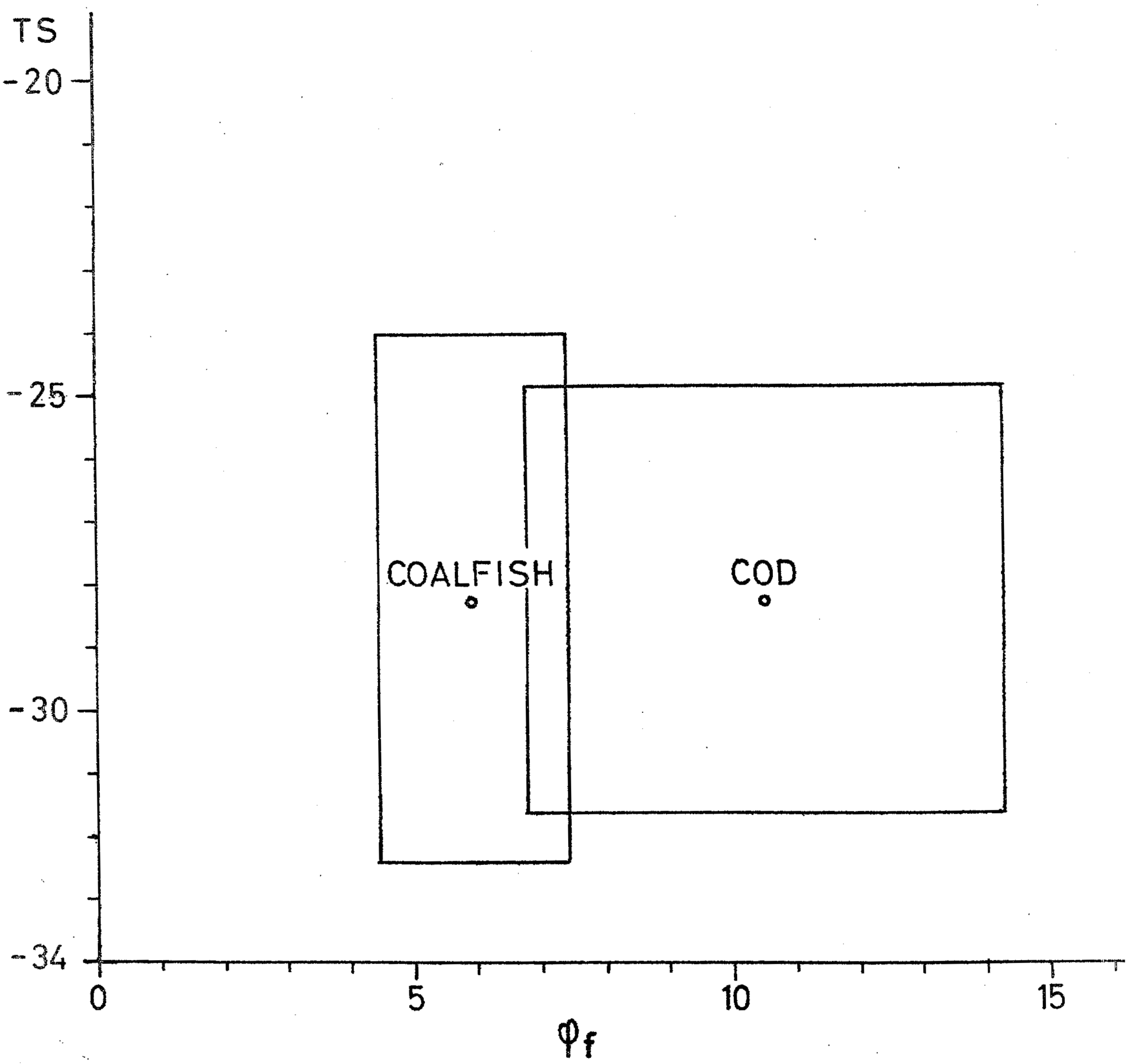

Fig. 7. φ_f - TS diagram showing mean values (points) and standard deviations (straight lines) of observed cod and coalfish.