On the Method of Inference of Standing Crop and Gregarious State of Nekton in a Fishing Ground by the Simultaneous Use of Two Echo-sounders of Different Directivities

Tasae KAWAKAMI*

(Received May 27, 1970)

If we scan a fishing ground by the simultaneous use of two types of echo-sounders which have different directivities, wide and narrow, different echograms of fish shoal will be obtained. From these echo-patterns, we have a gleam of hope to assess some gregarious state and abundance of shoals in the fishing ground. In this paper some considerations on this subject are given.

Let there be two independent systems of lines whose total lengths are L and S respectively in a given fishing ground of G in area. According to the mathematical theory of probability, the number, n, of points of intersection between both line systems is statistically given by

$$n = \frac{2}{\pi}\frac{LS}{G}. \tag{1}$$

Next, consider the case in which there distribute arbitrarily some domains whose total area is A in the above area G, and there exist randomly given lines whose total length is S over the same area, then the total length, s, of the parts which are included in the domain A is statistically given by

$$s = S\frac{A}{G}. \tag{2}$$

The ultrasonic echo-sounder emits high frequency sound waves in a definite solid angle, the width of which, that is to say the directivity of sound beam, is determined by both the frequency of sound and the size of transducer diaphragm. In Fig. 1, f denotes the area of a fish shoal and c the length of its circumference. An echo-sounder which has directivity of some definite angle, α, is scanning over the shoal by a research vessel and d is the horizontal distance from the margin of the shoal to the detectable limit of the echo-sounder. Then the area of domain in which the shoal can be detected by the echo-sounder is given by $(f + cd + \pi d^2)$, where πd^2 is the sum of areas of sectors which formed at the apex of the shoal polygon. Next consider the case in which there exist N shoals in the ground and let C denote the total length of their circumferences, F their total area,

* Dept. of Fisheries, Kyoto Univ., Maizuru, Japan. (川上太左英: 京都大学水産学教室)

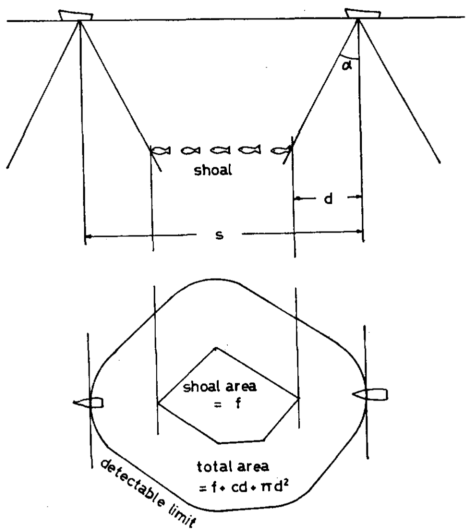

Fig. 1. Showing the relationship between the shoal area and the detectable area of an echo-sounder.

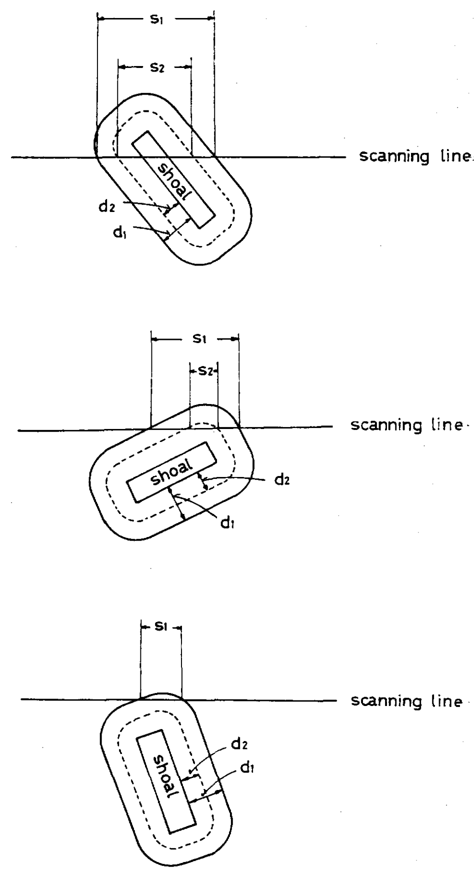

Fig. 2. Showing three different manners of appearance of fish-traces.

then the area, A, of the domain in which the shoal can be detected may be given by

$$A = F + Cd + \pi N d^2 . \qquad (3)$$

Now, when we scan the ground by an echo-sounder with scanning line of length S and obtained the fish traces of total length s, the following relation may hold:

$$F + Cd + \pi N d^2 = \frac{sG}{S} = sa , \qquad (4)$$

where $a = G/S$ is the mean distance between adjacent scanning lines.

Next, the fact that we get one echo-trace of fish shoal means that the scanning line interesect two times with the detectable line, the length of which may be given by $(C + 2\pi Nd)$. Let m be the count of echo-traces in this whole scanning operation, we have from Eq. (1)

$$2m = \frac{2}{\pi}\frac{(C + 2\pi Nd)S}{G} ,$$

giving

$$C + 2\pi Nd = \frac{m\pi G}{S} = m\pi a . \qquad (5)$$

Now, let us consider two echo-sounders of different directivities, of which the value of d are wide, d_1, and narrow, d_2. Then we scan the fishing ground by these two echo-sounders simultaneously, and obtain the echogram of fish shoal of s_1 and s_2 in length respectively. Some examples of appearance of echo-patterns in relation to fish shoal are shown in Fig. 2. From Eqs. (4) and (5) we have

$$F + Cd_1 + \pi N d_1^2 = s_1 a \,, \tag{6}$$

$$F + Cd_2 + \pi N d_2^2 = s_2 a \,, \tag{7}$$

$$C + 2\pi N d_1 = m_1 \pi a \,, \tag{8}$$

$$C + 2\pi N d_2 = m_2 \pi a \,. \tag{9}$$

Here the values of d are liable to change with the depth of the shoal, but the ratio:

$$r = \frac{d_2}{d_1} \tag{10}$$

will suffer rather small change if the frequency and the energy of both sounder waves are equal to each other.

Solving these equations (6)–(10) regarding d_1, d_2, N, C, and F as unknown we get

$$d_1 = \frac{2(s_1 - s_2)}{\pi(1-r)(m_1+m_2)} \,, \tag{11}$$

$$d_2 = r d_1 \,, \tag{12}$$

$$N = \frac{\pi(m_1^2 - m_2^2)a}{4(s_1 - s_2)} \,, \tag{13}$$

$$C = \frac{\pi(m_2 - r m_1)}{1 - r} \,, \tag{14}$$

$$F = \left[s_1 - \frac{(m_2 + (1-2r)m_1)(s_1 - s_2)}{(1-r)^2(m_1+m_2)} \right] a \,. \tag{15}$$

It is imposible to verify these equations in the actual fishing ground, hence some simulation trials by paper diagrams are carried out as an example shown in Fig. 3. Regarding a definite area G ($=840\ \text{cm}^2$) as a fishing ground, then draw on it some ($n=5\sim 10$) arbitrary quadrilaterals and a set of linear lines ($a=0.8\sim 1.7$), and regard former as fish shoals and latter as scanning lines. Thus the record of echograms is obtained assuming that $d_1 = 1$ cm and $d_2 = 0.5$ cm, hence $r = 1/2$ and obtained s_1, s_2, m_1, and m_2. The results are summerized in Table 1.

From these results the values of d_1, d_2, N, C, and F are calculated numerically, as shown in Table 2, in which the figures in parethesis are true values. The estimation of d is fairly satisfactory so far the scanning lines are dense as in this case. But as regards other values it seems rather tolerable for precise estimation. Next, some simulation trials for two special cases in which the shape of fish shoals is linearly elongated, having no width, and fishes distribute solitarily or non-gregariously, were made. The results are tabulated

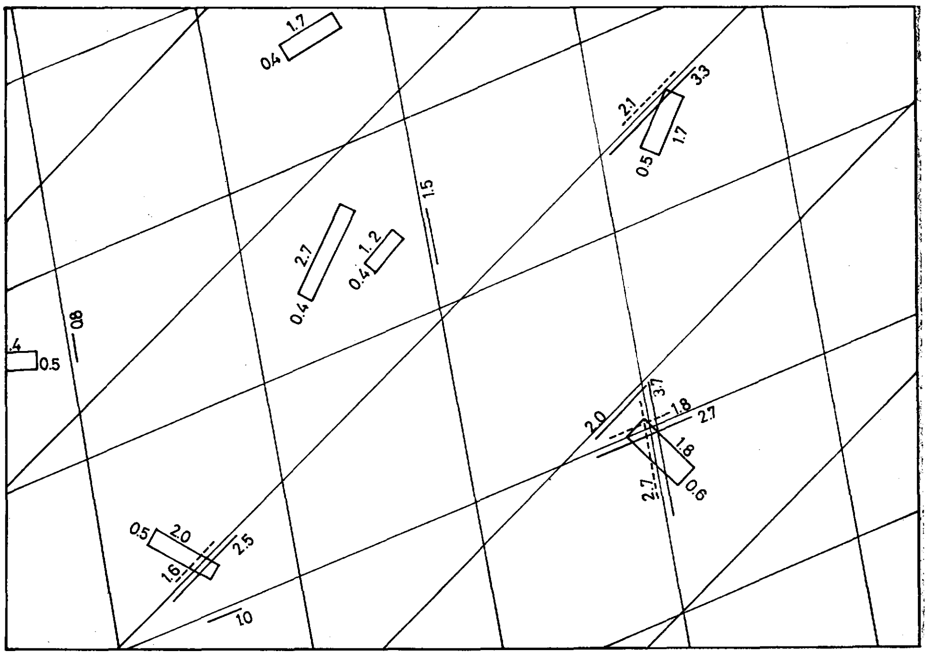

Fig. 3. Showing a part of simulation trial by paper diagram. Full lines and dotted lines along the scanning line denote the fish-traces obtained by the wide and the narrow echo-sounders respectively.

Table 1. Results of simulation trials.

Exp.	a	s_1	s_2	m_1	m_2
1	1.67	74.3	30.3	33	21
2	1.68	75.3	28.8	33	21
3	0.84	85.8	41.7	30	21
4	1.64	47.3	25.3	18	12
5	0.84	102.7	49.0	39	30
6	1.68	53.1	31.3	19	15

Table 2. Calculated values (actual values)

Exp.	d_1	N	C	F
1	1.04 (1.0)	19.3 (20)	47.3 (56.9)	9.7 (7.46)
2	1.14 (1.0)	17.5 (20)	47.5 (45.6)	4.9 (5.08)
3	1.10 (1.0)	6.8 (5)	31.7 (34.7)	11.1 (15.0)
4	0.93 (1.0)	10.5 (10)	30.9 (40.0)	19.8 (11.5)
5	0.99 (1.0)	7.6 (10)	55.4 (45.0)	7.8 (9.8)
6	0.82 (1.0)	8.2 (6)	58.0 (38.9)	24.7 (10.7)

Table 3. Results of simulation trials.

No.	a	s_1	s_2	m_1	m_2
1	1.69	34.1	13.5	17	12
2	1.67	65.8	25.4	33	23
3	1.66	63.6	22.1	31	20
4	1.67	53.2	17.6	30	18
5	1.66	41.3	23.2	25	15
6	1.67	43.5	15.2	27	17
7	1.83	24.9	5.6	18	8

Table 4. Calculated values (actual values).

No.	d_1	N	C	F
1	0.91 (1.0)	9.4 (10)	37.0 (26.2)	−0.2 (0)
2	0.92 (1.0)	18.2 (20)	68.2 (37.8)	−1.0 (0)
3	1.04 (1.0)	17.7 (20)	47.0 (39.8)	−2.3 (0)
4	0.99 (1.0)	21.2 (20)	31.5 (32.6)	−0.3 (0)
5	0.74 (1.0)	22.6 (20)	26.4 (0)	10.0 (0)
6	0.82 (1.0)	33.1 (20)	36.7 (0)	−0.8 (0)
7	1.07 (1.0)	12.0 (17)	5.6 (0)	−3.5 (0)

in Tables 3 and 4, which seem to show same tendency as above cases.

In order to keep the ratio r invariably regardless of the water depth, it is advisable to use sound wave of same frequency. This may be accomplished by the use of transducer diaphragm of different sizes, but we expect some difficultis to record the echo-traces separately unless some devices are made on the echo-sounder recording system. The other difficulty is that the absolute values of d may vary with the depth of shoal, hence the calculation should be made separately for each layer.

Some important suggessions were given by Dr. KUROKI of the Ocean Research Institute, Univ. of Tokyo, to whome the author wishes to express his sincere thanks.