SEAFDEC Training Department
current technical paper

Southeast Asian Fisheries Development Center

No. 9 April 1980

Experimental Echo Survey for Squid Fishing around the Phuket Waters

Keishi Shibata

and

Prasert Masthawee

Training Department

Southeast Asian Fisheries Development Center

Issued occasionally from the Training Department, Southeast Asian Fisheries Development Center,
P.O. Box 4, Phrapradaeng, Samutprakarn, Thailand.

Current Technical Paper Series No. 9
April 1980

Experimental Echo Survey for Squid Fishing around the Phuket Waters

by

Keishi Shibata

and

Prasert Masthawee

INTRODUCTION

An experimental echo survey in regard to squid handline fishing was carried out from 21-24 February 1980 on board a small research boat of the Phuket Marine Fisheries Station.

The aim of this survey was to detect fish and squid schools in the Phuket waters and to measure the target strengths of various fish and squids by means of a 50 kHz echosounder.

The present report deals with the method and various aspects of use of the 50 kHz echosounder. The authors have also attempted to evaluate the results obtained by its use, particularly its effectiveness in detection of fish schools.

APPARATUS AND METHOD

The transducer of the echosounder was installed on the starboard side of the front deck of the research boat and was carefully set perpendicularly at a depth of 1 meter in water.

The recorder of the echosounder was set on the steering table in the wheel house for convenient observation of echogram.

The specifications of echosounder used during the experiment in the Phuket waters are shown in Table 1.

Table 1. Specification of echosounder used for the experiment

Type	FURUNO FE 600A
Frequency	50 kHz
Depth range	0-40 meters
Sounding rate	360 per min
Pulse length	0.5 millisec, 75 cm in sea water
Beamwidth	50° in full angle between the half power angle points
Output power	125 watts
Recording paper	dry electrosensitive paper, 150 mm wide
Paper speed	3-30 mm/min, adjustable
Controls	range, white line, gain, output power, paper speed, TVG, etc.

1. Echo survey

Throughout the survey, various controls on echosounder were usually kept as follows:

Paper speed	:	3 mm/min
White line	:	magnitude 1
Receiving gain	:	magnitude 3
Output power	:	125 watts

The echo survey was carried out throughout the day from the running boat and only at night-time from the anchored boat. Various traces from individual fish of big sizes and also from fish schools could be obtained all around the Phuket waters.

2. Calibration and target strength measurements

The echosounder should be calibrated at the outset of an echo survey, because accuracy of estimating the size of individual fish or fish schools from echo trace depends entirely on accuracy of calibration of the echosounder.

The echosounder on the research boat was calibrated with a standard target, a pingpong ball of 40.5 dB in target strength. 1/

Calibration has to be carried out under following conditions:

i) The boat with echosounder should be anchored;

ii) The sound axis from transducer should be directed perpendicularly while the emitting surface of transducer should be held horizontally;

iii) Calibration should be done in the waters sheltered from wind and currents;

iv) The depth of test-waters has to be 20 meters or more;

v) The target has to be suspended just on the sound axis in suitable depth of 10 meters or more;

vi) Any sound obstacles including a sinker have to be set on the suspending line of the target at enough clearance - longer than the transmitted pulselength in water - and the line has to be as fine as possible to avoid sound reflection from the line;

vii) When calibration or target strength measurement is done only by means of sensitive gain control without any electronic tools, i.e., an attenuator, osciloscope etc., a cross-relation diagram between the echo level in dB and the magnitude of sensitive gain control, i.e., 1, 2, 3, ... 9, 10 has to be prepared in the workshop before going to sea, as shown in Fig. 1.

1/ The target strength of a spherical air bubble is:

$$Ts = 20 \log_{10} (R/200) \text{ in dB}$$

where, R is the radius of the sphere.

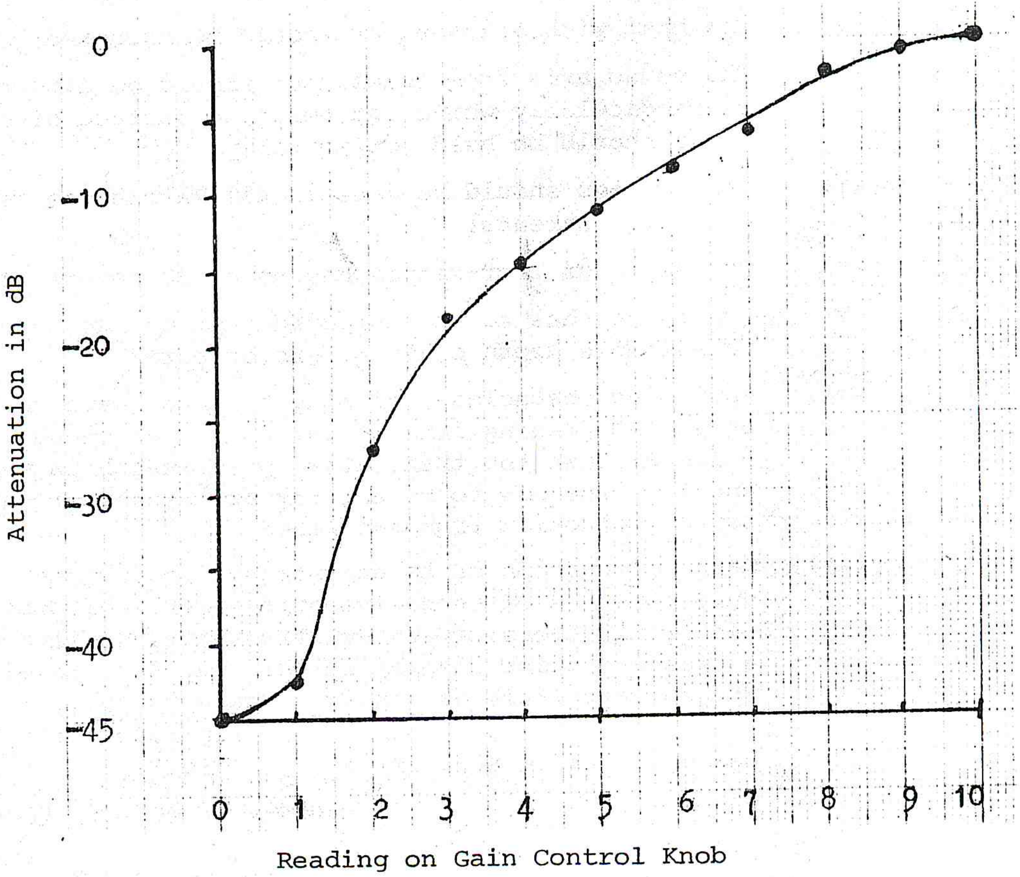

Fig. 1 Diagram for interpreting GAIN control magnitude into dB value.

In the experiment, acoustic measurements were made by means of a suspending frame(Fig. 2) which had been constructed on board the research boat. The following materials were used:

i) monofilament nylon lines of 0.4 mm in diameter;

ii) two electric welding rods about 30 cm long;

iii) small fishing hooks with fine nylon lines;

iv) a sinker of 2 kg.

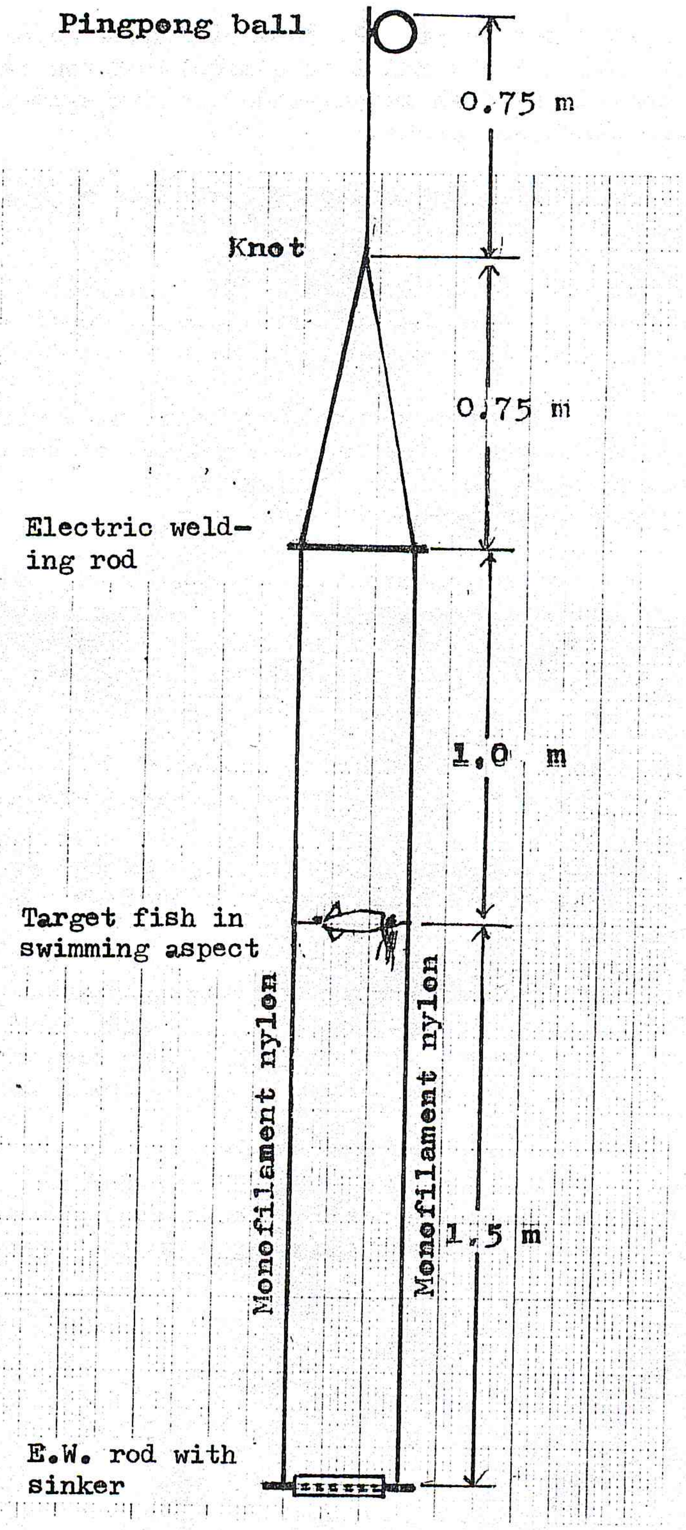

Fig. 2 Suspending frame of target for calibration and target strength measurement.

As shown in Fig. 2, the horizontal welding rods are connected with the nylon lines and in the middle of the resulting rectangular space the target fish is suspended in its swimming aspect by means of two fine lines and hooks.

Meanwhile, the standard target is tightly fixed above the frame and the sinker is fixed onto the lower rod.

It should be noted that the intervals between the components of the frame, i.e., the standard target, upper rod, fish and lower rod, are longer than the pulse length of 0.75 m.

While the echosounder was calibrated with the aid of a pingpong ball, simultaneously the target strength of squids of various sizes was also measured by means of the suspending frame; the procedure for measurement is described below.

When the standard target (a pingpong ball) and the target fish had been placed in position, the frame was carefully lowered into the water. At the same time air-bubbles which were attached to the targets were carefully removed, because air, especially when trapped in the mouth and the body cavity of the fish, often greatly affects the target's echo strength.

After checking for air-bubbles on the targets, the frame was suspended in water at a depth of about 10 meters. The position of the frame was checked through observation of the echogram so as to obtain the strongest echo from the targets because the strongest echoes from them were obtained just on the sound axis.

Fig. 3 shows a typical echogram during the measurement of target strength of fish. In this figure, a dense line at 9-meter depth is from the pingpong ball, further lines are in order of the depth, the upper welding rod, the target fish and the lower rod with a sinker.

During the echogram observation, the knob of sensitive gain control was slowly turned until the respective line of echo from the target disappeared and minimum reading of the gain control knob was taken, with the corresponding depth on the recording paper.

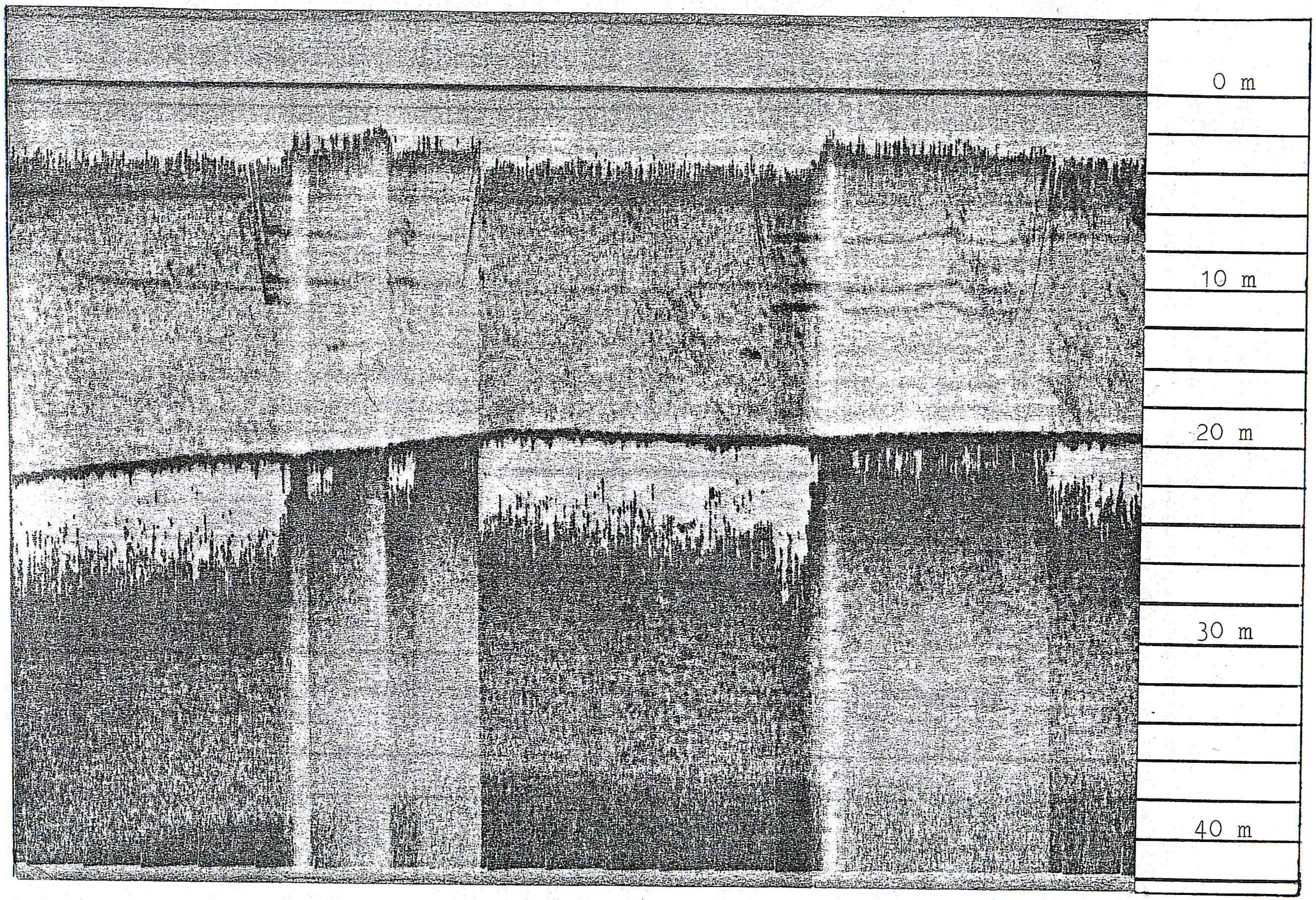

Fig. 3 Typical echogram from the suspending grame during the calibration and target strength measurement.

CONSIDERATIONS

Although echo traces could not be clearly identified within the range of the experiment, echogram identification should become possible in Thai waters by means of comparative review of both the fish caught and echo traces registered in the same waters.

Generally, marine fish swim in different layers in the day and night-time and some of them form schools in the daytime and scatter at night. This phenomenon was also observed in the Phuket waters during the echo survey.

The echo trace of an individual target was recorded as a fingernale trace or inversed V shape, and the echo trace of a dense fish school appeared as a comet trace with a long tail produced by the sound reverberation among the school.

1. Echo trace from individual fish

Theoretically, the echo pulse from an individual target is the same in length as the transmitted pulse, whereas the echo pulse from multiple targets is longer than the transmitted one.

The analogical informations which can be obtained on the echogram are the shape of echo trace (corresponding to the size of fish, swimming direction and speed of fish) and the swimming depth of fish.

A theoretical illustration for changing depth within an echo trace from a single fish is shown in Fig. 4. In this figure it is assumed that (1) the boat is running from A to B and C with a constant speed and course, (2) a single fish is stationary at the point F at the depth of D, and (3) the detectable range in angle is θ for the fish.

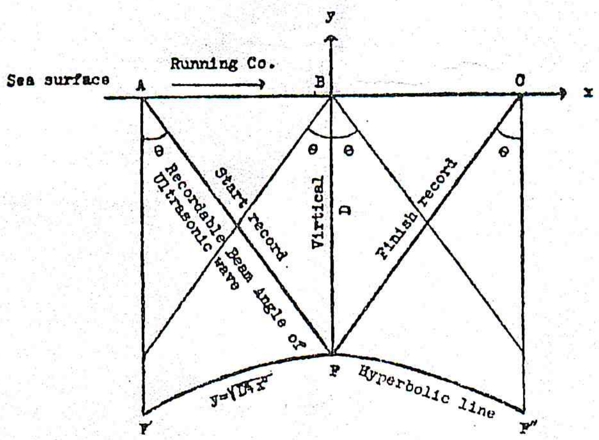

Fig. 4 Diagram of the recording process from a fish.

The detectable angle θ varies with the output power, the receiving gain control of the sounder, target strength of fish, depth of fish, shape and size of the transducer and the operating frequency; it never has a constant value as shown in the manufacturer's catalogue. (See Fig. Ap-2)

As shown in Fig. 4, the echosounder began to record the fish F at point A; at point B the ship was just above F and it finished recording F at point C,

$$AF = D^2 + AB^2$$

$$CF = D^2 + BC^2$$

$$BF = D$$

from the assumptions (1) and (2),

$$AB = BC$$

$$AF = CF = D'$$

$$\theta = \cos^{-1}(D/D')$$

The depth of fish within an echo trace apparently varies with the angular direction relative to the fish; the true depth of fish is only given as the minimum depth of the fish trace on the sound axis. When the fish passes off center of the sound beam, the apparent depth of fish will be estimated as greater than its true depth.

The shape of echo trace from an individual fish varies also with the ship's speed as shown in Fig. 5. These illustrations are given theoretically for a certain target fish for various ship's speeds from 2-10 knots.

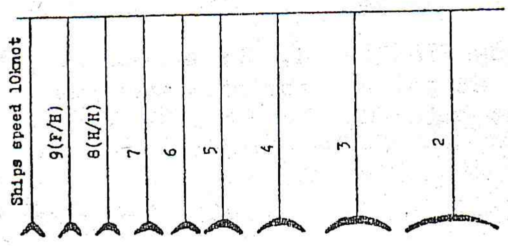

Fig. 5 Changes of echo traces of fish at various ship's speeds.

The width of echo trace, B, is determined according to the following equation:

$$B = 2mh. \tan \theta/(V_s \mp V_f)$$

where, m is the paper speed, h is the minimum depth within an echo trace as shown in Fig. 6, θ is the above mentioned maximum detectable angle and V_s and V_f are the ship's speed and fish swimming speed respectively. Since in many cases the swimming speed is very low in comparison with the ship's speed, V_f may be disregarded.

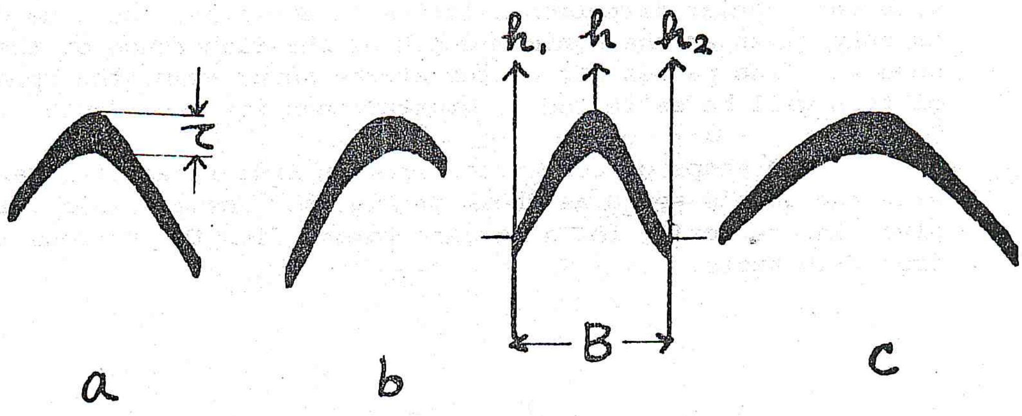

Fig. 6 Various shapes of echo trace from individual fish with different swimming directions.

Theoretically, the size of fish and its swimming speed can be estimated roughly from the data contained in an echo trace of fish, by applying this equation.

Generally, identification of fish trace from a single target or from multiple targets such as a fish school can be made by comparing the thickness of fish trace and the thickness of the transmission line on the top of the echogram as mentioned above. The thickness of the echo trace from fish is measured at its shallowest point as shown in Fig. 6-a.

For example, assuming the thickness (pulse length) is τ_o for the transmission line and is τ for fish trace:

i) individual fish trace : $\tau \leq \tau_o$

ii) fish school : $\tau > \tau_o$

iii) seabed echo : $\tau \gg \tau_o$

This method has recently been applied in the integrating circuit for estimating fish stocks by means of acoustic system.

Fig. 6 gives examples of echo traces from individual fish with various vertical components of swimming speeds. The fish in Fig. 6-a is diving to deeper water (a-type); inversely the fish of b-type is swimming to shallower water whereas the fish of c-type is stationary i.e. it has no vertical component of swimming speed.

If all fish traces are recorded as b-type, the emitting surface of the transducer will be installed with some inclining angle forward of the ship. This trend may arise when the emitting surface of the transducer was installed parallelly to the keel line, because in most cases the ship has a trim by the stern in the fishing ground.

If B in Fig. 6-c is abnormally long (short) in comparison with the other traces in the same waters, the fish may be working in the same (inverse) direction of the ship's running course. The size of B may vary with the ship's speed or the swimming speed of fish but in many cases the swimming speed is negligible.

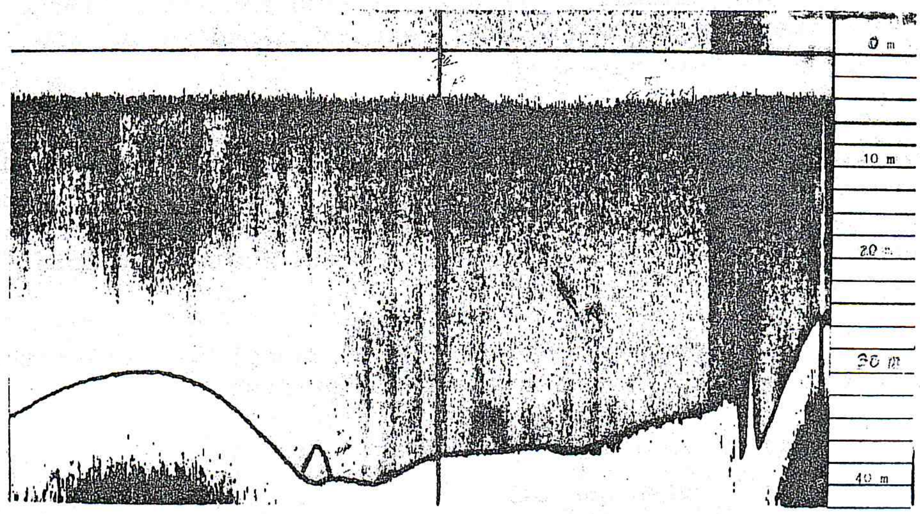

Fig. 7 Echo trace of gig fish with 50 kHz sounder, FE 600A, at 20h 30m on 24 February 1980, near Ko Ka Island in the Phuket Bay.

This fish was the biggest one recorded throughout the echo survey in the Phuket waters from 21-25 February 1980. From the size of the echo trace the fish was estimated to be 50 cm in full length (see Appendix - 2).

Fig. 7 shows an example of a typical echo trace from a large single fish; this echogram was obtained near the Ko Ka Island in the Phuket Bay at 18h 05m on 24 February 1980, with a 50 kHz echosounder. The fingernale trace at the depth of 36 meters was estimated to be from a shark, because the maximum detectable angle was calculated about 57° or more from this trace and a fishing boat nearby was operating handline fishing of shark (see Appendix - 2).

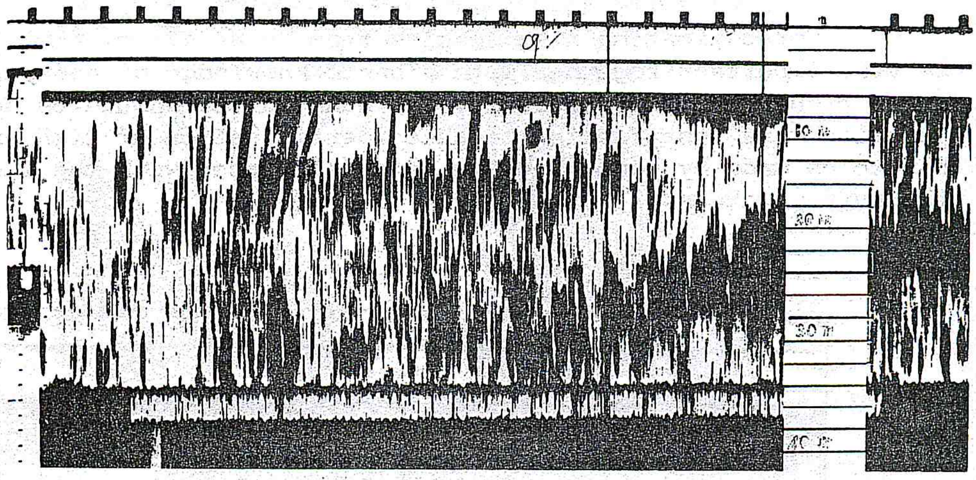

Fig. 8 Typical echogram of fish school with a 200 kHz sounder of Pramong 10, at 23h 00m on 22 February 1980 in the western waters off Phuket Island.

Fig. 8 gives a typical echogram with the depth range of 0-40 m, produced by a 200 kHz echosounder with narrow beamwidth of 6° (installed on R/V Pramong 10 of the Phuket Research Station). The echogram was taken in the western waters off Phuket Island between 21h 35m - 22h 00m on 22 February 1980, while the boat was anchored at 32 m deep of water gathering fish by means of attracting lamps.

The echo pattern of a 200 kHz echosounder with narrow beam is quite different from the pattern of a 50 kHz sounder with wide beams. Narrow beams are capable of recording traces of individual fish in a school.

In this echogram, the vertical or oblique lines are echo traces from individual fish and the dense massive trace on the right hand side represents a fish school, attracted by lamps at the depth of 15-24 meters.

By a trial calculation based on the oblique traces of individual fishes, the swimming speed was estimated as 0.18 - 0.43 m/sec or more. If the sounder is properly calibrated, the swimming speed of fish can be determined with considerable accuracy.

2. Echo trace from fish school

The echosounder was operated continuously throughout the survey around the Phuket waters and large number of fish schools were recorded. Mr. Niyom, a research officer of the Phuket Marine Fisheries Station, identified them as a sort of sardine.

For estimating fish species from an echogram, empirical judgment is very important together with a basic knowledge of acoustics as well as of fisheries. Particularly, the echo survey should be done in conjunction with test fishing because identification of fish on an echogram has to be made by comparing the recorded traces with the fish caught in the survey waters.

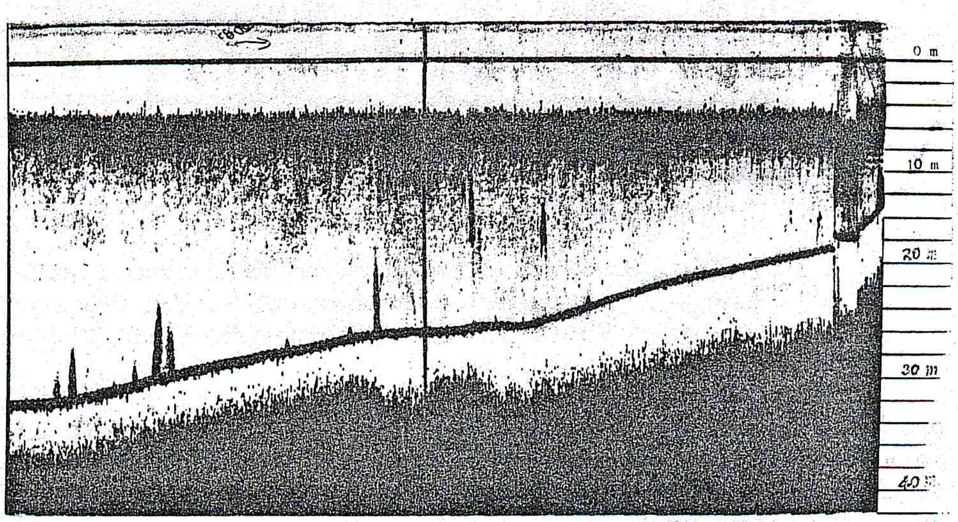

Fig. 9 Typical echo trace of fish around the shallows in the western waters off Phuket, recorded at 15h 00m on 22 February 1980.

Fig. 9 is a typical echo trace of fish school, obtained in the western waters off Phuket Island around 15h 00m on 22 February 1980 with the echosounder of 50 kHz. During this recording the boat was running with a speed of 2 knots.

In this figure, many vertical comet-traces from fish schools can be seen between the seabed and 10 or 6 meters deep. The faint horizontal lines from 6 to 10 at the right-hand side of the echogram are due to the noise induced by irregular vibrations of the transducer. Whenever such lines are observed, the installation system of the transducer should be carefully checked.

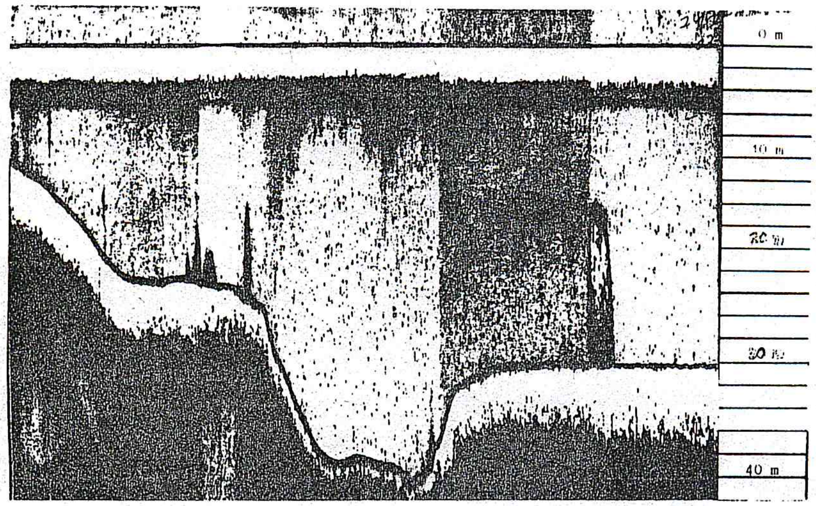

Fig. 10 The biggest echo trace from a fish school, recorded with the 50 kHz sounder in the southern waters Pipidom I in Phuket Bay, at 14h 15m on 24 February 1980.

Fig. 10 is another typical echo trace from a large fish school which was obtained in the southern waters nearby the Pipidom Island in the Phuket Bay at 14h 15m on 24 February 1980, with the 50 kHz sounder.

This fish trace was the biggest one throughout the research cruise and it was thought to represent a very densly concentrated fish school because the effect of the white line, which identifies the strong echo from the seabed, acts also on this echo trace of fish school.

Fig. 11 gives a typical echogram with the 50 kHz sounder of fish schools attracted by lamps at 11h 30m on 22 February 1980 in the western waters of the Phuket Island.

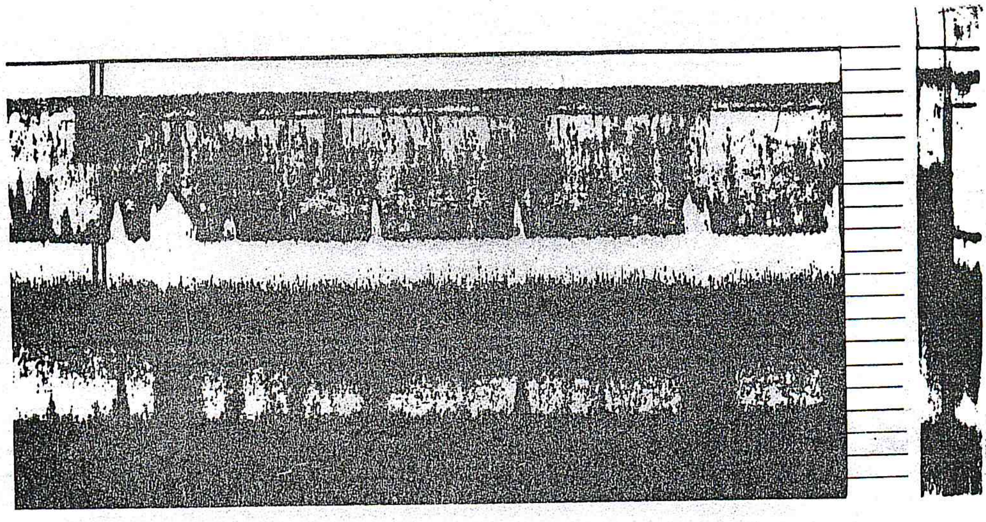

Fig. 11 Typical echogram of fish school gathered around the attracting lamps.

This echogram was obtained with the 50 kHz sounder at 23h 30m on 22 February 1980 in the Kam Mara Bay off Phuket Island.

In this figure, the second echo from seabed or echo from dense fish schools is shown at the bottom side; the fish schools swim near the seabed around the light of the attracting lamps whereas individual fish and small fish schools are observed in the surface layer.

An early stage of gathering fish with attracting lamps in the Kam Mara Bay is also shown in Fig. 12.

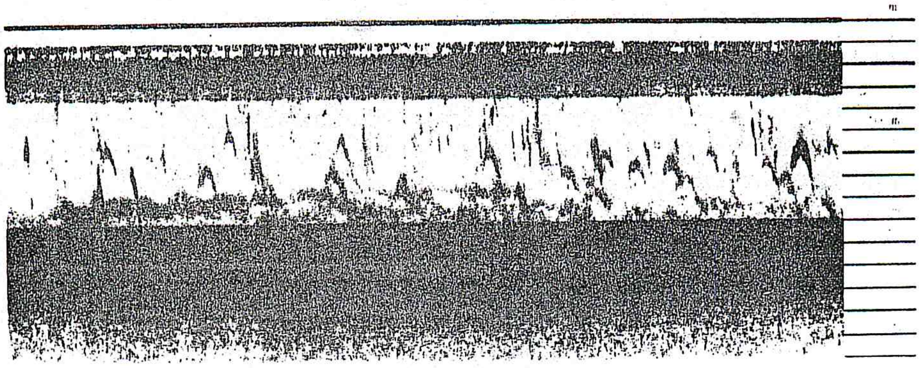

Fig. 11 Echogram of fish school attracted by lamps.

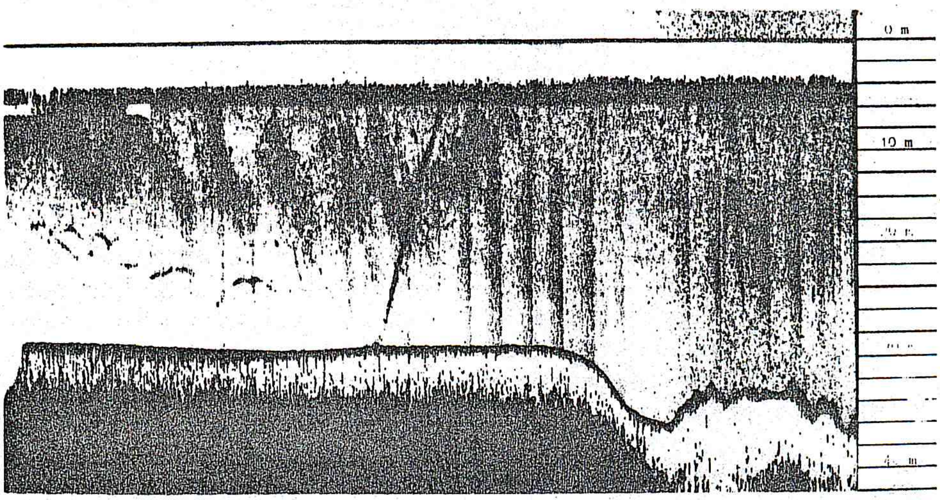

Fig. 13 Echo trace from an anchor of the research boat with the 50 kHz sounder. During the recording time, the anchor was being pulled up manually.

Fig. 13 shows an echo trace from an anchor of the research boat, recorded with the 50 kHz sounder. On this figure, an oblique line at the center part shows heaving aspect of the anchor and at the left hand side of it several irregular echo traces are from individual fishes with various swimming motions.

At the time of this recording, the anchor was being hove up by hand from the seabed, 28 m deep.

3. Calibration and target strength of fish

Calibration of the 50 kHz echosounder, which was used throughout the survey, was carried out on two occasions with a pingpong ball as a standard target of - 40.5dB; at 13h 00m 22 February 1980, near the Ko Ka Island in the Phuket Bay.

After calibration had been repeated 12 times, the source level was determined as 121 dB in relative level.

As mentioned earlier, the reading of the sensitive gain magnitude was obtained at the instant when the echo disappeared on the recording paper by carefully turning the knob of the gain control on the front pannel of the echosounder, and the reading was interpreted into dB in relative level on the diagram of Fig. 1.

A series of measurements on the target strength of squid was carried out parallelly with this calibration.

Such parallel measurements on the standard target and fish target is very convenient for checking their positions relative to the sound axis, because the strongest echo is obtained when the target is set just on the sound axis. And also, even in the worst case, the target strength of the fish can be determined in comparing the two echo levels from the standard target and from the fish target because the difference of the angular directions between them relative to the sound axis is practically negligible.

Measurements of target strength of fish were made on 6 squids from 11 to 19 cm in mantle length and on 5 fishes of various sizes. The target strength of squid, *Loligo formosana*, was determined to be from - 47.5 to - 38 dB, as shown in Fig. 14.

In fig. 14, the ordinate is the relative echo level in dB referred to the minimum recordable level, and the abscisa is the distance of a target or the seabed from the transducer in logarithmic scale. Furthermore, the relative values in dB corresponding to the magnitude scale of the sensitive gain control are also given on the vertical axis on the right side from Fig. 1. The thick line at the magnitude 3 is the background noise level observed in the Phuket waters by the 50 kHz sounder. The line at magnitude 2 corresponds to the level of minimum recognizable signal (MRS) of 10 dB above the noise level.

Accordingly, the echo with higher level than the MRS can be distinctly identified among the background noise.

In the upper part of the left vertical axis, values for the maximum and minimum target strength of squids are given in dB, as well as estimated area-scattering-strength for seabed.

From this figure, the maximum detectable depth of squid may be determined from 20 to 30 m of the values on the horizontal axis at the crossing points of the oblique curves for squids and the horizontal line of MRS.

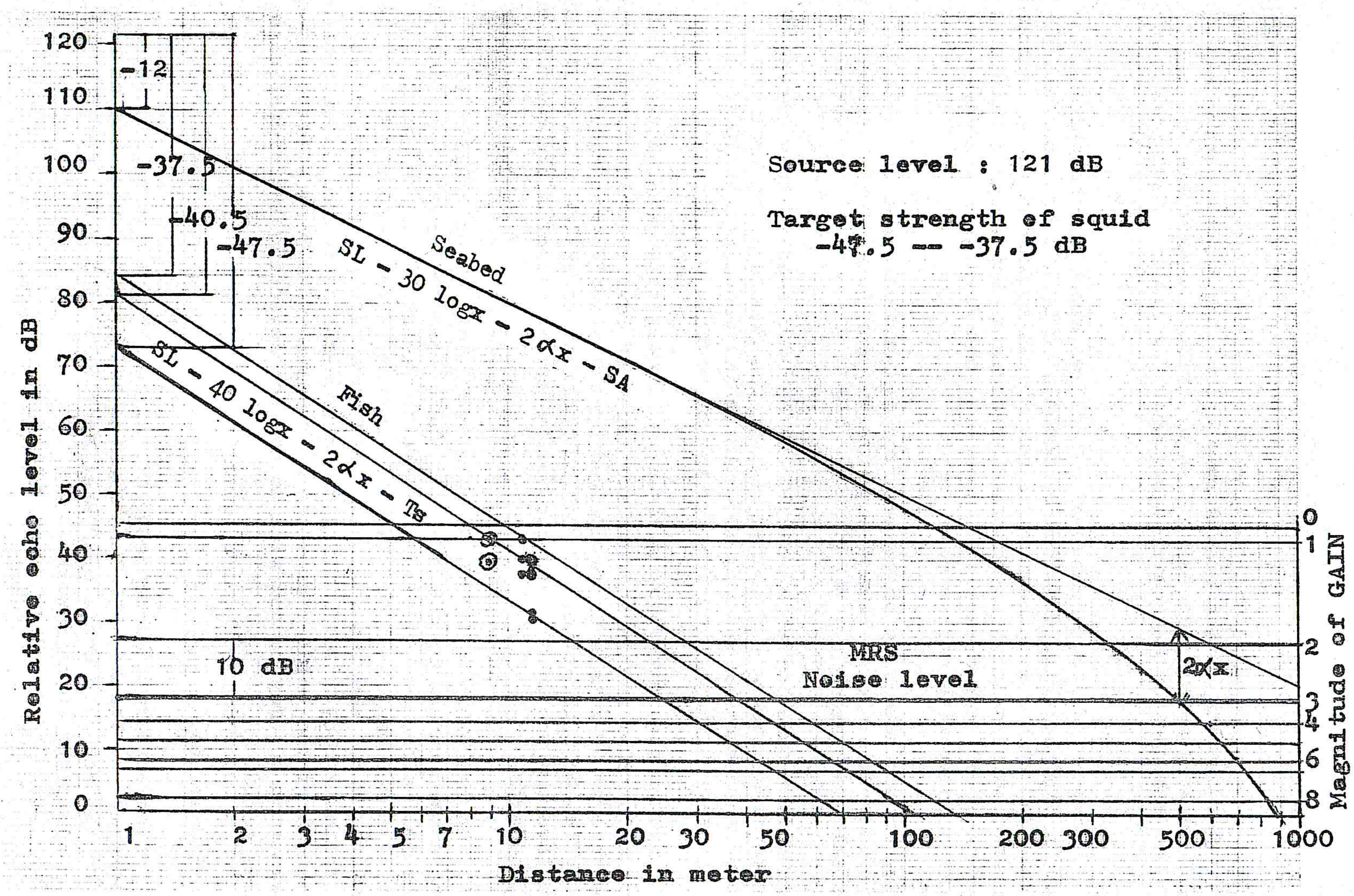

Fig. 14 Diagramatic solution of sonar equation for the calibration of the 50 kHz echosounder and target strength measurements of fish in the Phuket waters.

CONCLUSION AND SUMMARY

The results of the echo survey around the Phuket waters may not yet cover general aspects of fish distribution in these waters, since the echo survey was carried out only for a very short period of 3 days.

However, a large number of dense fish schools, thought to be a sort of sardine, were observed by means of a 50 kHz echosounder. This sounder with a wide beam angle of 50° was evaluated to be suitable for use in purse seining in Thailand, because an echosounder with a beamwidth of 50° can detect fish school around far wider area than a 200 kHz sounder with narrow beams of 10° or less.

Unfortunately, echo traces from squids could not be clearly identified; this should become possible in near future with the aid of empirical observation.

After calibration of the 50 kHz sounder used in this survey, and the target strength measurements, it was demonstrated that the sounder can detect an individual squid at maximum depth of 20 to 30 m, when the sensitive gain control is set at magnitude - 3.

It is very difficult to identify echoes from fish swimming in layers below 30 m and in the surface layer of less than 10 m. Detection in depth over 30 meters is restricted by the signal/noise ratio, particularly in the night-time. It may be possible to reduce this background noise level by use of STC circuit, or by use of rather sharp beamwidth of transducer.

On the other hand, the high noise level of the shallow layer may have been caused by the depth of the transducer, which was installed on the hull side, at 1 meter below the surface. Since the depth of the transducer was shallower than the bottom of the research boat, the beamwidth of 50° and the side beams may have received strong echoes from the hull body itself. This phenomenon can be solved by extending the length of the holding pipe and by reducing side beam effects and the beamwidth of 50° may be too wide to use for detecting individual fish such as squid.

Acknowledgements

The authors are indebted to Mr. Niyom, Phuket Marine Fisheries Station, Mr. M. Yesaki, FAO Tuna Fishing Project in Phuket and also the crew of the research boats of Phuket Marine Fisheries Station for their kind assistances on this work.

Acknowledgement is due to one of the authors and Mr. Y. Kitagawa of Yo Fishing Tackle Mfg. Co. for valuable advice on fishing.

APPENDIX - I Fundamentals for analysing echo-survey data

1. Directivity pattern function of transducer

The directivity pattern function of a transducer is defined as follows:

$$b(\theta) = I_x(0)/I_x(\theta)$$

where, $I_x(0)$: Sound intensity at a given distance, x, from a transducer on the sound beam axies

$I_x(\theta)$: Sound intensity at the same distance on a given angular direction from the sound axies, θ

The directivity pattern function, $b(\theta)$, varies with the angular direction, θ, around the sound axies from 1 on the axies to zero and also varies with the shape of transducer and sound frequency. For example,

$$b(\theta) = (2\,J_1(z)/z)^2 \quad \text{for cylindrical transducer} \qquad (1)$$

$$b(\theta) = (\sin(z)/z)^2 \quad \text{for rectangular transducer} \qquad (1')$$

$$z = (\pi d/\lambda)\sin\theta \qquad (2)$$

where, J_1 is the first sort of Bessel function, d is the diameter (length of reference side) of cylindrical (rectangular) transducer, and λ is the wavelength of soundwave.

2. Sonar equation for an individual target 1/

$$EL = SL - 40\log_{10}r + Ts + 20\log_{10}(b(\theta)) \qquad (3)$$

where,

EL : echo level which is received at the transducer in dB

SL : source level which is measured at the reference point of 1 meter or 1 yard from the transducer on the sound axies. In the case of the echosounder used in Phuket water, SL = 121 dB.

r : distance of a target from the sound source

Ts : target strength

1/ R.J. Uric (1967) "Principles of Underwater Sound" (book), McGraw-Hill, New York, p. 187-198.

3. Target strength of fish

The target strength of fish varies with the shape, size and aspect of fish and operating frequency of echosounder and will be approximated by the following formula (McCartney, 1971):

$$Ts = 24.5 \log_{10} L - 4.5 \log_{10} \lambda - 26.4 \quad (m, dB) \quad (4)$$

where, L is the overall length of fish and λ is the wavelength in meters.

This experimental formula is given for the dorsal aspect of fish. The target strength of fish depends largely on the size of the swimbladder of fish. Accordingly, a fish without swimbladder will have weak target strength.

Furthermore, Ts will fluctuate with the direction of sound beam relative to the fish body. However, in the case of vertical echosounder, the target strength will depend only on the dorsal aspect of fish.

Table AP-1. Target strength of various sizes of fish for operating frequency of 50 kHz from Eq(4) for the dorsal aspect.

L_{oa}	(cm)	10	15	20	25	30	35	40	50	75	100
Ts	(dB)	-44	-40	-37	-34	-33	-31	-29	-27	-23	-20

4. Sonar equation for comparatively wide multiple target 1/

$$RL_v = Sl - 40 \log r + Sv + 10 \log V \quad (5)$$

$$V = (\tau C/2)\Psi r^2$$

which may be written as:

$$RL_v = SL - 20 \log r + Sv + 10 \log \left(\frac{\tau C}{2}\Psi\right) \quad (5')$$

where, $\frac{\tau C}{2}$: Pulse length, τ is the pulse length and C is the sound velocity in sea water.

Ψ : Beamwidth of ideal equivalent two-way beam patter steradian, for short cylinder transducer, $10 \log \Psi = 20 \log (\lambda/\pi d) + 7.7$ dB

RL_v : Volume reverberation level

Sv : Back-scattering strength of unit volume of water

1/ ibid.

5. Back-scattering strength of fish school

The value of Sv should be determined from the field experiment with a fish school of known size in survey waters, but its approximation will be possible as follows:

$$\overline{Sv} = \overline{Ts} + \sqrt{\rho} \qquad (6)$$

where, $\overline{Sv}$ and $\overline{Ts}$ are averages for Sv and Ts throughout the survey waters and ρ is the density of fish school, or a number of fish contained in the unit volume of sampled water.

For example, when the number of fish in volume unit of water was observed by visual methods, i.e., underwater camera and skin diving, as n fish/m^3 and the average length of fish within the fish school was $\overline{L}$, $\overline{Ts}$ could be calculated from Eq(4) and $\overline{Sv}$ may also be obtained from Eq(6).

APPENDIX - 2 Applications of theory to field measurements

A target strength of fish can be theoretically calculated from a fish trace on an echogram as follows:

1. Identification of echo trace from individual fish or from fish school

This identification method was already explained in Fig. 6. If it is from an individual fish, the maximum and minimum depths, h and h_1, on the upper rim of the echo trace should be measured on the echogram.

2. The maximum angular range of the fish detected by means of the echosounder, θ_{max} is:

$$\theta_{max} = \cos^{-1}(h_1/h) \qquad (9)$$

3. Drawing a directivity patterns of the transducer used

The transducer used in the Phuket waters is 5.5 cm in diameter of the circular surface and the emitting wave length is 3 cm. According to Eq (2):

$$z = (5.5\pi/3) \sin\theta$$

Fig. AP-1 is the directivity pattern of sound beams of the 50 kHz echosounder used in the Phuket waters. In this figure, the two-way pattern function, 20 log b(θ) in dB is taken on the vertical axis and the directional angle around sound axis is given on the horizontal axis in degrees.

As shown in this figure, the beamwidth is very wide in the main-beam and the half-power angle is about 25°.

4. Drawing the two-way actual beam pattern for respective Ts.

The actual two-way beam pattern which could detect a fish of a certain size at a certain depth, will be given when EL = 0.

For example, since the echo sounder was operated at the magnitude-3 of sensitive gain control throughout the survey and SL was calibrated as 121 dB in relative source level, SL' = 121 - 21 = 100 dB from Fig. AP-1.

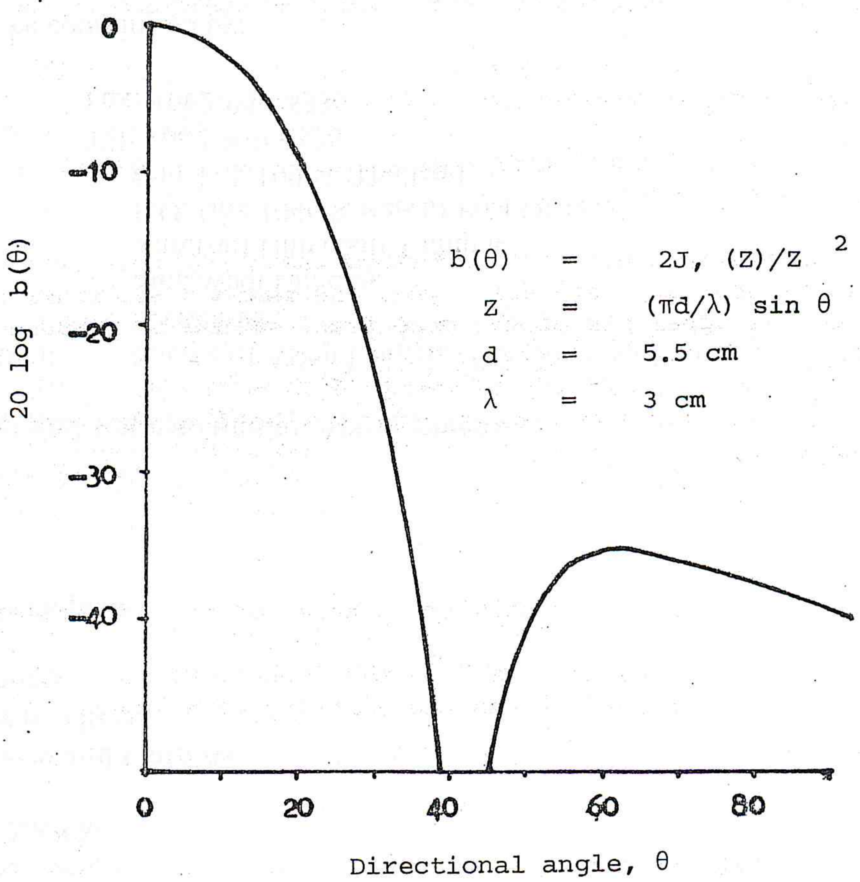

Fig. AP-1 Diagram of directivity pattern function of the 50 kHz echosounder used in the Phuket waters.

When EL = 0, the echo margin on the sound axis, M is:

$$M = -20 \log b(\theta),$$

accordingly, Eq(3) will be written:

$$-20 \log b(\theta) = 100 - 40 \log r + Ts \qquad (9)$$

where, is the maximum detectable range in angular direction for a fish in depth r and a certain size of Ts, and this angle will be calculated from Eq(1) or Eq(9).

Fig. AP-2 is the actual two-way beam pattern which is calculated by following parameters of various depths of fish, by 5 meter steps, and various target strengths, by 5 dB.

Table AP-1. Respective parameters of Ts and depths of fish and calculation results. (SL = 100 dB)

1. Margin on the sound axis in dB.

Ts r(m)	5	10	15	20	25	30	35	40	45
-20 dB	52	40	33	28	24	21	19	16	14
-25	47	35	28	23	19	16	14	11	9
-30	42	30	23	18	14	11	9	6	4
-35	37	25	18	13	9	6	4	1	
-40	32	20	13	8	4	1			
-45	27	15	8	3					

2. Maximum detectable angular range in degree from Fig. AP-1

										main	side-lobe
Ts r(m)	5	10	15	20	25	30	35	40	45	r_{max}	r_{max}
-20	40 (44,77)	36 (50,78)	34	32	31	29	28	26	24	100	13
-25	38 (47,86)	35 (65)	32	30	28	26	24	21	19	75	10
-30	37 (49,81)	33	30	27	24	21	19	16	13	56	7.5
-35	36 (55,75)	31	27	23	19	16	13	6		42	5.0
-40	34	28	23	18	13	6				32	4.2
-45	32	25	18	12						24	31
-50	28	21	12							18	1.5

Remarks: (digits) are for the side lobe.

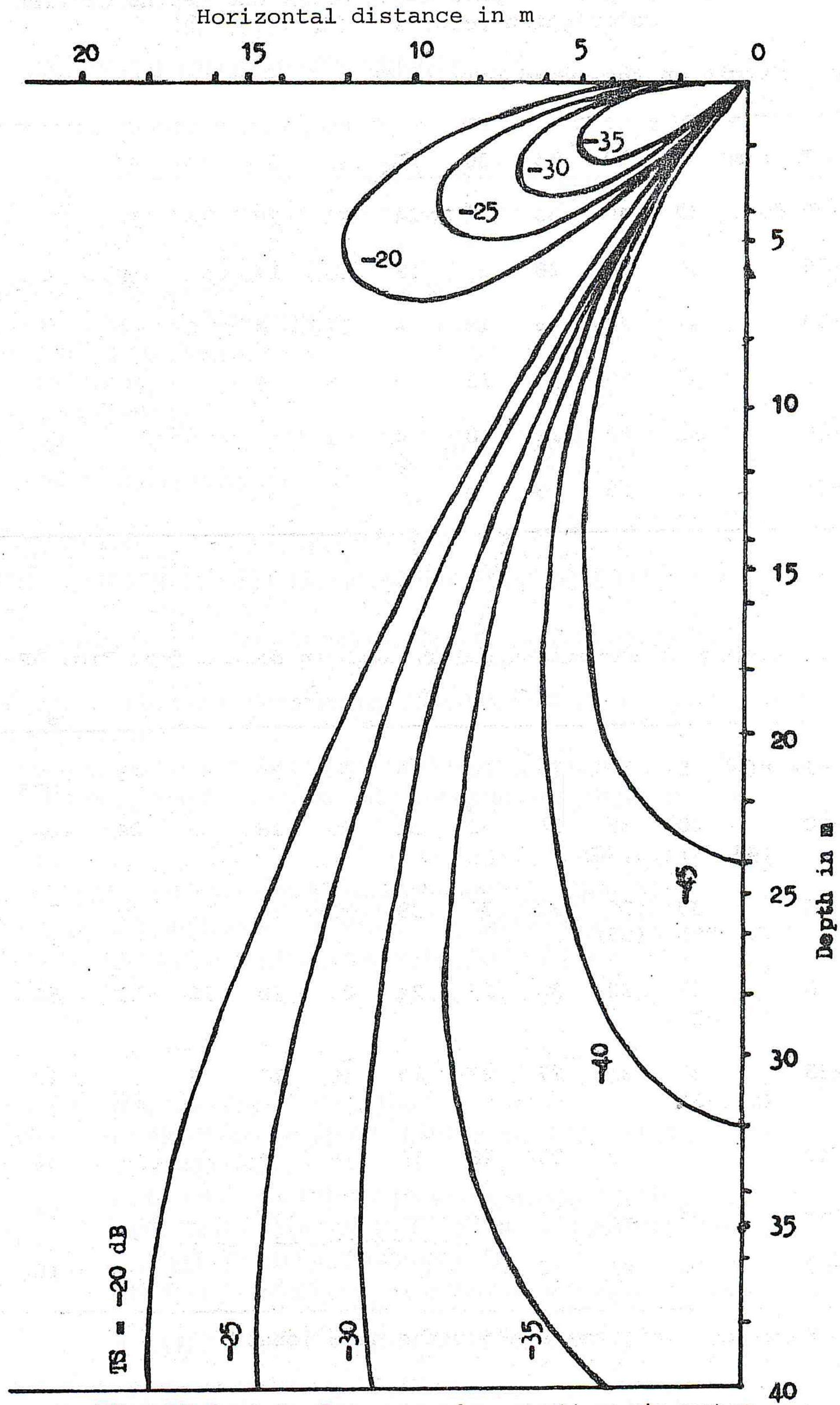

Fig. AP-2 Actual two-way beam pattern in water for respective size of fish (target strengths).

In Fig. AP-2, the depth and horizontal distance are taken in the same scale on both axis and each curve for the respective target strengths from -20 to -50 dB by 5 dB steps shows the detectable area enclosed from 0 - 40 m deep, corresponding to fish of respective target strength.

The areal integration of detectable area enclosed by respective curve is commonly used for determining the density of fish school.

For example, when a number of fish traces, N, was counted on the echo chart from r_1 to r_2 in depths during a given running distance of the survey boat, ℓ, the sampled volume of water, V is:

$$V = \ell \cdot \sum_{i = r_1}^{i = r_2} A_i dr$$

where, $\Sigma A_i dr$ is the areal integration of enclosed figure on the actual two-way beam pattern from r_1 to r_2.

And density of fish is:

$$\rho = N/\overline{V} \qquad (10)$$

5. Example of calculation of fish size from echo trace

The biggest echo trace of individual fish as shown in Fig. 7 was measured as h = 34.2 m and h_1 = 37.6 m. The detected angular range for this fish is:

$$\theta = \cos^{-1}(h/h_1) = 24.6^{\circ}$$

Accordingly, the echo margin on the sound axies is from Fig. AP-1,

$$-20 \log b(\theta) = 16 \text{ dB} (=EL)$$

then, on Eq(3)

$$16 = 100 - 40 \log 34 + Ts$$

$$Ts = -100 + 61 + 16 = -25 \text{ dB}$$

furthermore, from Eq(6) and $\lambda = 30$ cm

$$-23 = 24.5 \log L - 4.5 \log 0.03 - 26.4$$

$$\log L = (-23 - 6.9 + 26.4)/24.5 = -7.5/24.5$$

$$\therefore L = 51 \text{ cm}$$

The size of the biggest fish recorded in the Phuket Bay will be estimated as 50 cm in overall length of fish. As mentioned earlier, it was thought to have been a shark since other sharks were being caught near the survey boat at the time.