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Study on the Relationship Between Acoustic Backscattering Strength and Density of Larval Anchovies

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The relationship between backscattering strength and fish density is a scaling factor of quick acoustic assessment method. It will affect the accuracy of estimating results. In fact, engraulid larva (anchovy) is so weak and small, it is impossible to form simulating school by using live fish. The dead fish used to simulate fish school by sinking through a 0.83 cm × 0.83 cm mesh size sifter in anechoic tank is described in this paper. Fish density ranging from 170 inds./m^3 to 14,226 inds./m^3 were insonified by a pressure pulse at a carrier frequency of 200 KHz. The received echo signals were recorded on magnetic tape, digitized and processed in a microcomputer to obtain the average backscattering strength of each model school. In a joint effort with underwater optical method to determine the instantaneous actual fish density of model school. The results are summarized as follows:

(1) The average backscattering strength is in proportion to the density of the model school under 1000 g/m^3. Below this critical density, it is possible to estimate the standing crop of engraulid larvae by quick acoustic assessment method.

(2) The individual target strength of engraulid larva is weak ranging more or less between −101.8 dB and −94.1 dB. Therefore, the fish density recorded on the echogram by echo sounder is very light.

(3) The regression line between the average target strength (Ts) and and the logarithm of mean body length (BL), Ts = 26.42 Log (BL) − 110.65, is obtained from this study, with a correlation coefficient of 0.98.

Key words: *Acoustic estimation, Average backscattering strength, Schooling of engraulid larvae*

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INTRODUCTION

The "shirasu" fishery or "larval" fishery is one of the most important coastal fisheries in Taiwan. Its catches reach 3,165 tons with the value of about 572,605 thousand NT dollars in 1988. The catch species was mainly composed of Family Engraulidae (anchovies) and about 5% other economic species (Sun, 1988). Because of its importance in commercial catches and its possible effect on the inshore fisheries resources, abundance and biology of engraulid larvae have been paid attention for a few years (Chen, 1980, 1982, 1984). Owing to the lack of the information on the recruitment of engraulid larvae and the standardization of fishing gear and fishing method, it is difficult to standardize the fishing effort which

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result a failure of estimating abundance statistically. Lee *et al.* (1988) firstly tried to study the estimation of the biomass of fish larvae recorded on the echogram by echo sounder and proposed by using patch number, area and volume as the index of biomass. Nevertheless, the fish density was found to be variable with space and time. Therefore, the present study of estimating the standing crop of engraulid larvae by echo integrator (Lee, 1985; Lee *et al.*, 1987; Wu *et al.*, 1987) must be proceeded against time (Lee *et al.*, 1988). Moreover, the accuracy using acoustic method is determined by the scaling factor, in other words, it is determined by a precise measurement of the relationship between average backscattering strength ($\overline{SV}$) and fish density (Furusawa, 1983; Lee *et al.*, 1986). There are always two methods to be concerned in this study:

(1) Measuring the relationship between $\overline{SV}$ and fish density (Aoyama, 1982; Burczynski *et al.*, 1982; Johannesson and Losse, 1973; Lee *et al.*, 1987) in simulated school by balls or dead fish in anechoic tank.

(2) Measuring the backscattering strength in simulated school by changing fish density in a cage with live fish of known species and size (Aoyama, 1982; Burczynski *et al.*, 1982; Johannesson and Losse, 1973).

Since the engraulid larva is so weak and small, it is impossible to form simulating school by using live fish. The present study describes a method to get the scaling factor for estimating the standing crop of engraulid school in coastal waters of Taiwan.

MATERIALS AND METHODS

Engraulid larva sample

The engraulid larvae were collected during April 23 and May 30 in 1989 by pair-trawl from the coastal waters ranging between Lin-Pien estuary and Feng-Kang estuary at the depth of shallower than 30 m. The samples were kept in ice box and brought back to the laboratory. The acoustic response of model school was measured immediately in the tank once the samples arrived. The lengths of

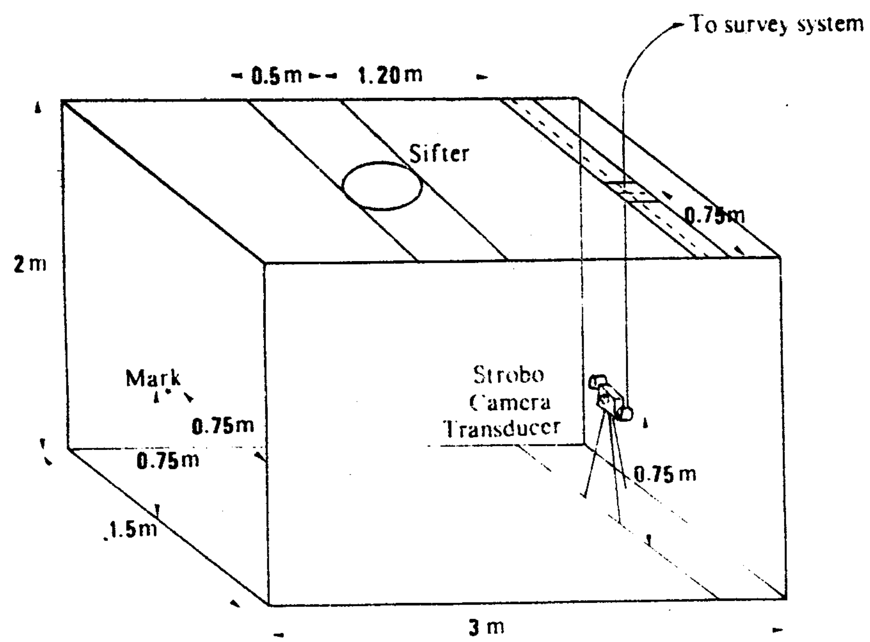

Fig. 1. Set up the instruments in the anechoic tank.

catches ranged from 1.5 cm to 4.5 cm and which were divided into three categories: 1.5 cm-2.5 cm, 2.5 cm-3.5 cm and 3.5 cm-4.5 cm. The backscattering strengths of engraulid school at different density among these three length groups were estimated.

Experiment instruments

The experiment was proceeded in a 3 m × 1.5 m × 2 m anechoic tank with the necessary setting as indicated in Fig. 1. The block diagram of the acoustic system (Lee *et al.*, 1987) was shown in Fig. 2. One 50 cm × 50 cm sifter with the mesh size of 0.83 cm × 0.83 cm, placed on the top of the tank allowed the engraulid larvae to sink through the sifter by gravity, and the larvae were insonified by acoustic beam of the survey system. Size and density of the simulated fish school were decided by the working range and the amount of engraulid larvae tested. Experiments were conducted four times, and 20, 21 and 13 model schools were formed by the three length classes respectively. Table 1 lists the weight, mean body length, mean weight of the 1.5 cm-2.5 cm larvae of a simulated school and horizontal extension width of echogram recorded by echo sounder. The weight of the simulated schools (Fig. 3) varied from 5 g to 6000 g.

Firstly, the larval engraulids of adequate weight were sifted into the water through the sifter. The sinking time of engraulid fish were counted and the trigger were recorded on the magnetic tape. For the measurement of instantaneous backscattering strength, photographs of the simulated school in the anechoic tank were taken and memorized immediately in the tape counter with

Table 1. Acoustic, visual and biological data of 1.5-2.5 cm engraulids used in this experiment (1989 June 1)

Model number	Mean body weight	Mean body length	Weight of model school	H (cm)	H/v (min)	Photograph No.
1	0.0343	2.23	5 g	0.45	0.113	1- 3
2	0.0343	2.23	10 g	0.69	0.173	4- 8
3	0.0343	2.23	20 g	0.70	0.175	9-12
4	0.0343	2.23	30 g	0.71	0.178	13-18
5	0.0343	2.23	50 g	1.41	0.353	19-24
6	0.0343	2.23	80 g	1.50	0.375	25-30
7	0.0343	2.23	100 g	1.71	0.428	31-37
8	0.0343	2.23	200 g	2.21	0.552	38-44
9	0.0343	2.23	300 g	3.02	0.755	45-52
10	0.0343	2.23	400 g	2.30	0.575	53-55
11	0.0343	2.23	500 g	3.11	0.778	56-60
12	0.0343	2.23	600 g	3.43	0.858	61-67
13	0.0343	2.23	800 g	3.25	0.812	68-76
14	0.0343	2.23	1000 g	2.75	0.688	—
15	0.0343	2.23	1500 g	4.20	1.050	—
16	0.0343	2.23	2000 g	3.30	0.825	—
17	0.0343	2.23	3000 g	4.50	1.125	—
18	0.0343	2.23	4000 g	4.10	1.025	—
19	0.0343	2.23	5000 g	4.40	1.065	—
20	0.0343	2.23	6000 g	4.75	1.750	—

H, horizontal extension width; v, paper speed (cm/min)

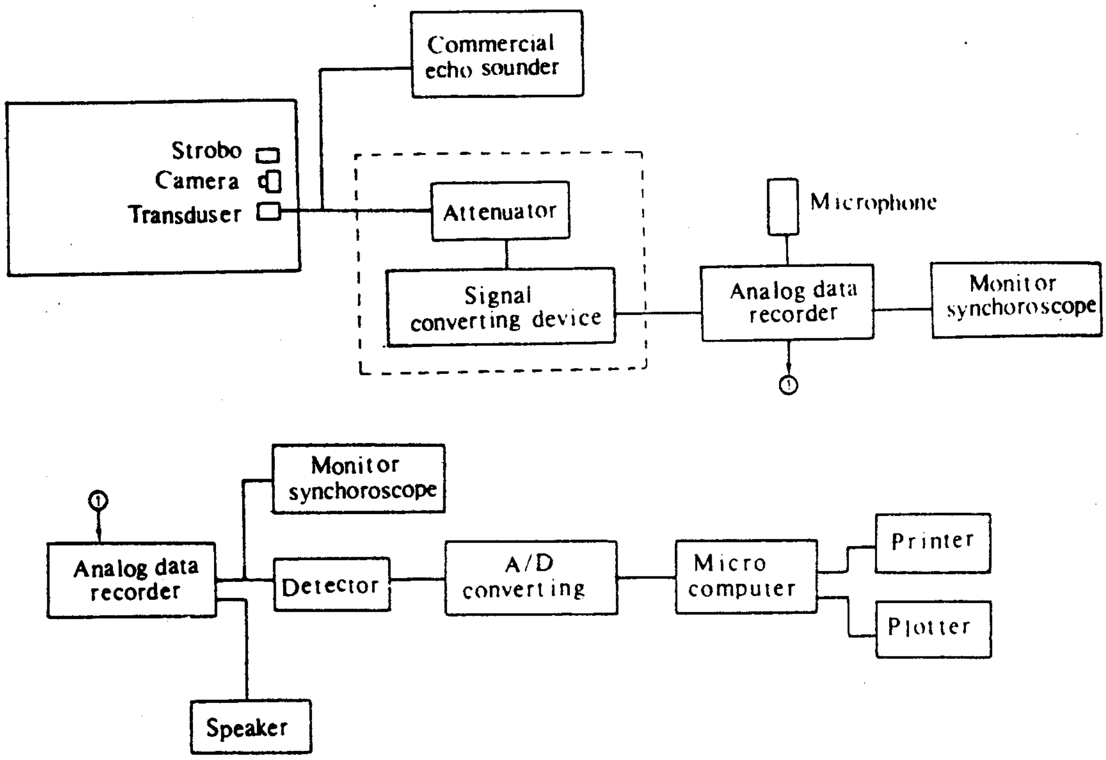

Fig. 2. Arrangement and block diagram of the acoustic system.

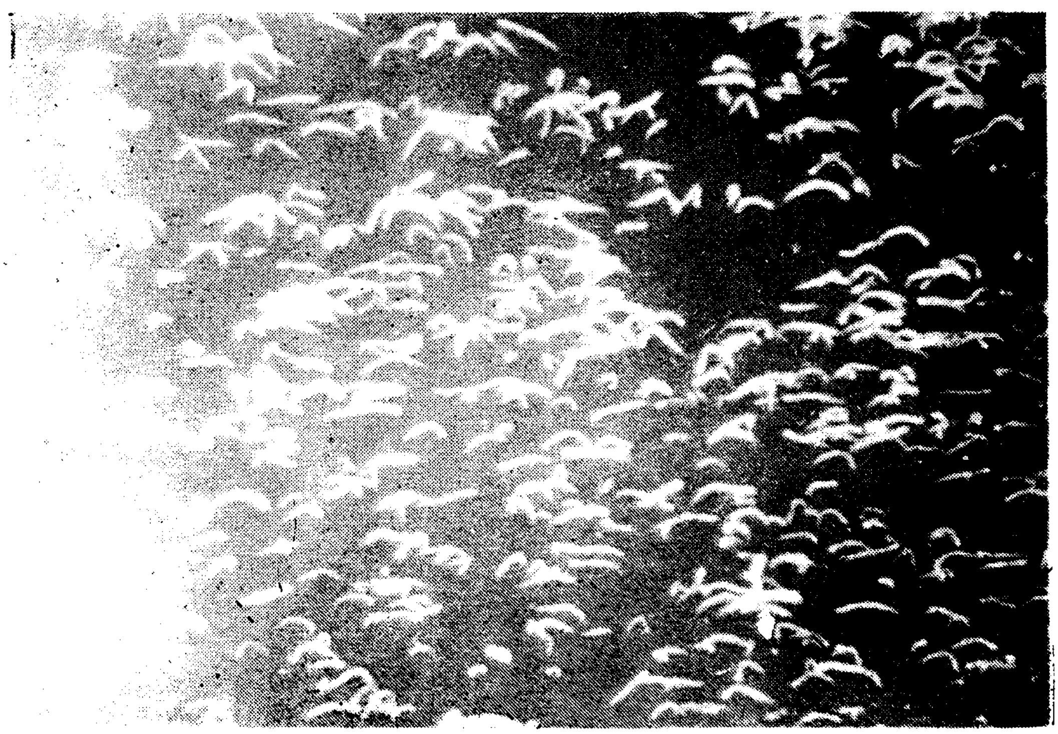

Fig. 3. Photograph of simulated school taken by underwater camera.

the setting condition on the FM track by microphone when the flash light was working. The recorder was turned off when the echo signal was lost.

Data analysis

Instantaneous and average backscattering strength of engraulid larvae: The tapes were played back and were monitored on the synchroscope. Listen to the audio memory in order to confirm the signal of simulating school. The analog signals were then input to microcomputer and were converted digitally by A-D converter contained in the microcomputer. The processing occurred as real time, and the sampling frequency was 25 KHz (1 sample/3 cm). Moreover, a half amplitude pulse width method (Lee *et al.*, 1987; Long and Hamada, 1983) was used to remove the noise. Finally, the retained echo level data were converted into electrical levels on the terminal of the transducer (in dB) according to the sonar equation (Burczynski, 1979; Lee, 1985). The instantaneous backscattering strength (SV_i) of this response pulse was calculated by the echo integrated method (Lee, 1985; Lee *et al.*, 1987). The average backscattering strength was obtained from the mean of SV_i of all echo signals (Wu *et al.*, 1987).

Estimation of average fish density

The diameter of the sifter is 50 cm and the working range is 60 cm. The size of $X-Y$ plane where the engraulid school fallen in was $50\times 60\,\text{cm}^2$. The volume of engraulid school was given by

$$V = v \times t \times 50 \times 60/10^6 \ (\text{m}^3) \tag{1}$$

Where v, the sinking velocity (cm/sec) of engraulids, and t, the time of simulating school recorded (sec).

Thus, the average fish density is obtained from:

$$\overline{D}\,(\text{g/m}^3) = w/V \tag{2}$$

and

$$\bar{\rho}\,(\text{inds./m}^3) = w/(V \times \bar{w}) \tag{3}$$

where w, the weight of total engraulids simulated, and $\bar{w}$, the mean weight.

Visual determination of instantaneous fish density

As shown in Fig. 4, the optical axis of the camera was X axis, and the plane including X axis was $X-Y$, and the Z axis intersects perpendicularly the $X-Y$ plane. The center of the lens is o. If half angle in rolling plane of the camera was α and half angle in pitching plane was β, the horizontal width was $2x \tan\alpha$ and the vertical length was $2x \tan\beta$ at x point on the optical axis. Thus the cross section $A(x)$ was expressed as:

$$A(x) = 4 \cdot \tan\alpha \cdot \tan\beta \cdot x^2 \tag{4}$$

For measuring α and β, scale ruler was perpendicularly set to the optical axis (Fig. 5). Moreover, it was placed horizontally or vertically at 170 cm away from the camera. Therefore, pictures taken from underwater camera showed the roll and pitch limits relative to the 170 cm point away from the camera ($\overline{PQ}$ and $\overline{PR}$ in Fig. 5). Point P was the center of the scale ruler at 170 cm away from the reference point o on the optical axis. $\overline{OP}$ was a known figure (170 cm), thus $\overline{PQ}$ and $\overline{PR}$ were obtained as 23 cm and 15.9 cm respectively which were determined by the picture taken. These data were analysed by the following two formulae:

$$\alpha = \tan^{-1}\,(\overline{PQ}/\overline{OP}) \tag{5}$$

$$\beta = \tan^{-1}\,(\overline{PR}/\overline{OP}) \tag{6}$$

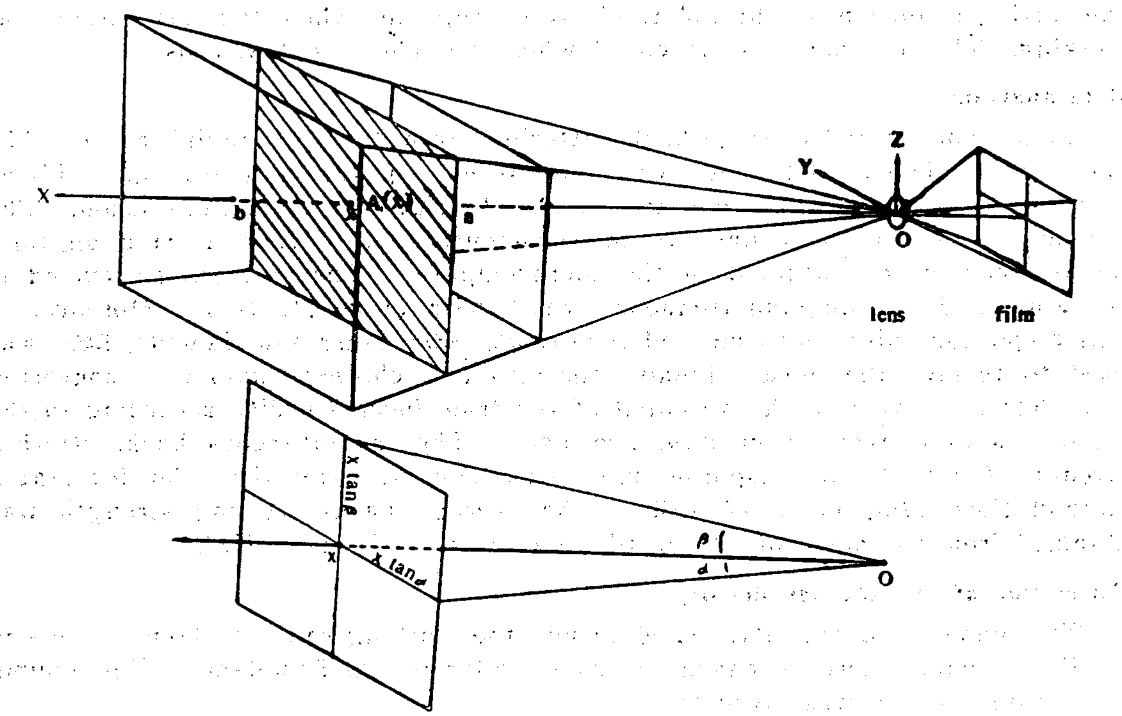

Fig. 4. A scheme showing how the volume of one picture taken by underwater camera was obtained.

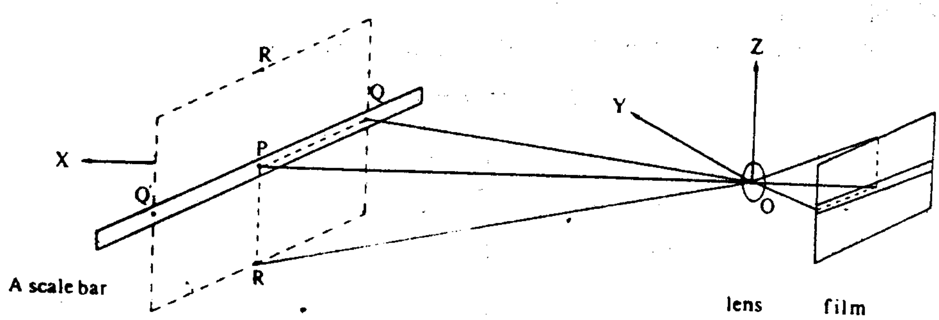

Fig. 5. A scheme showing how the angle in rolling plane and in pitching plane of one picture taken by underwater camera was obtained.

From which 7.7° and 5.3° were obtained respectively for the angles α and β with the field of view of camera at 15.4° × 10.6°. The covering volume of the camera (V) was expressed by:

$$\begin{aligned} V &= \int_a^b A(x)\, dx \\ &= \int_a^b 4 \tan\alpha \cdot \tan\beta \cdot x^2 \cdot dx \\ &= 4/3 \tan\alpha \cdot \tan\beta \cdot (b^3 - a^3), \qquad (7) \end{aligned}$$

where $A(x)$, the function of cross section, and a and b (120 cm and 170 cm) were two focus points of the camera, and the volume covered by the camera was gained as 0.053 m³. Then the density of fish passing underneath the transducer can be expressed as $D = n/V$ (inds./m³), where n, the number of fish shown on the photograph (Fig. 3).

RESULTS AND DISCUSSION

When the fish density is lower than 1000 g/m^3, the average backscattering strength increases linearly in density. When fish density is higher than 1000 g/m^3, the increment no longer exists. Lee (1985) and Lee and Aoyama (1986) reported that the relationship between $\overline{SV}$ and simulated school density is positively related under a certain density. Hence, this critical density of engraulid larvae is about 1000 g/m^3 (Fig. 6).

The relationship between average backscattering strength and logarithm of the fish density (g/m^3) for the three length groups is positively linear under the above critical density (Fig. 7). When the fish density is expressed in the number per unit of water volume or abundance (inds./m^3), their relationships remain positively linear resulting from the F test with high significance at the level of 0.01.

201 photographs of simulated school among three length groups were taken by underwater camera. Fish density in number (abundance) ranged from 170 to 14,226 inds./m^3. The instantaneous backscattering strength is measured accordingly, and the relationship between the instantaneous backscattering strength (SV_i, in dB) and the instantaneous simulated school density of each photograph in 1.5 cm–2.5 cm length class is established (Table 2; Fig. 8). Both the average and the instantaneous backscattering strength are in proportion to the logarithm of the fish density below 1000 g/m^3, but the two linear regression lines do not overlap (Fig. 8). According to Lee and Aoyama (1986), the school density could be estimated under the critical density and the variation of results were not significantly influenced by the distribution of fish within the fish school. Hence, the slight differences of the two relationships for average and instantaneous backscattering strengths are independenton ochooling patterns and may be caused by the sinking

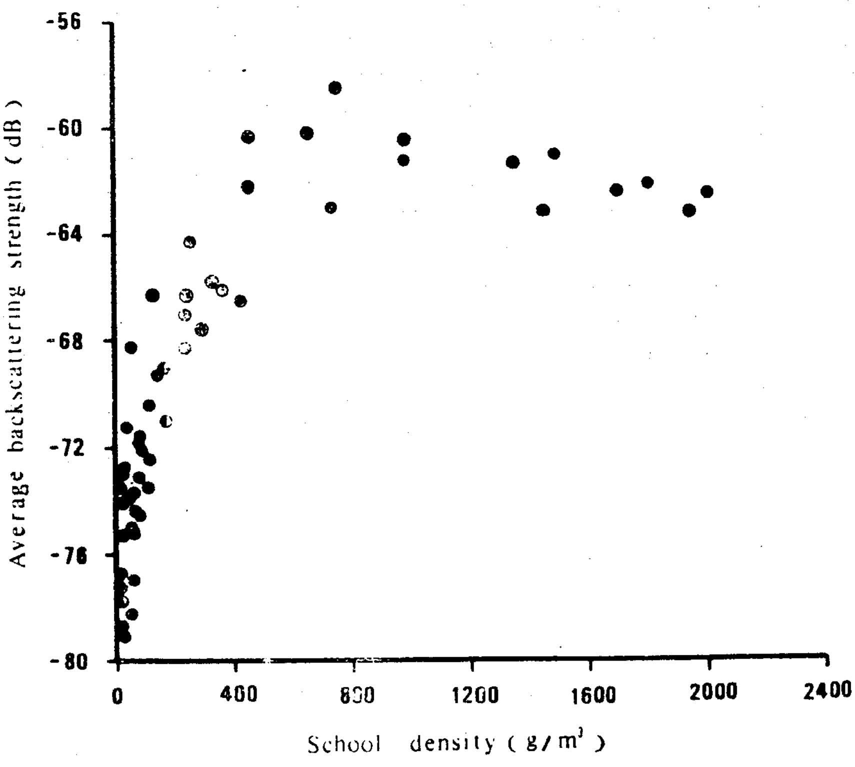

Fig. 6. Relationship between average backscattering strength and average density of simulated school.

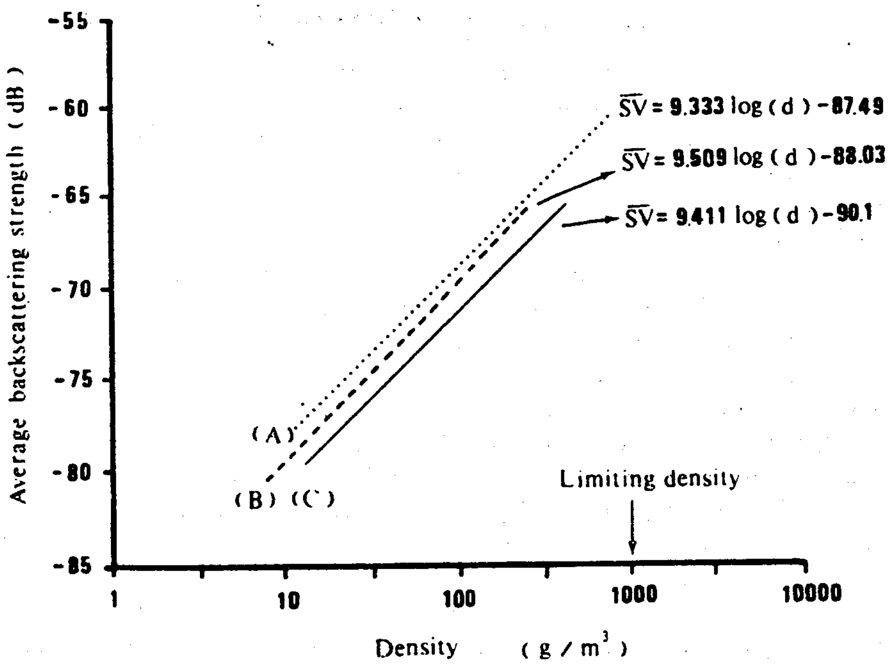

Fig. 7. Relationship between average backscattering strength and the logarithm of average school density. d, simulated school density; (A), 1.5-2.5 cm length class; (B), 2.5-3.5 cm length class; (C), 3.5-4.5 cm length class.

velocity which was supposed to be a constant in this experiment. In fact, as shown in Fig. 9, the density of fish indicated on the echogram of the same simulated fish school decreased as the simulated school lasted. In other words, the sinking resistance of the simulated school density insonified by the acoustic beam increased with the continuous appearance of the simulated school. Subsequently, a decrease in sinking velocity was expected. Therefore, the volume observed in the experiment was greater than the actual volume, thus the observed simulated school density was less than actual school density. Hence, the regression line between the average back scattering strength ($\overline{SV}$, in dB) and the logarithm of average school density (inds./m^3) is higher than that between the instantaneous backscattering strength (SV_i, in dB) and the logarithm of the instantaneous school density (inds./m^3). But, as shown in Fig. 8, the broken lines were within 95% confidence limits of the solid lines among three length classes respectively. Thus the bias of the method for estimating the abundance of engraulid larvae using the average backscattering strength can be neglected.

Individual engraulid larva was so weak and small and gathered together, that the target strength measured by suspend method in anechoic tank or direct observation method in situ was impossible. However, Holliday and Pieper (1980) reported that the relationship between the average backscattering strength ($\overline{SV}$) and the target strength (Ts, in dB) was as follows:

$$\overline{SV} = 10 \log D + Ts \qquad (8)$$

Hence, the target strength of engraulid with 2.23 cm mean body length is weak with about -101.8 dB. If, the individual fish of larval patch at 30 m deep is recorded echo-soundly with 6 dB minimum recordable level and 167 dB source level calculated from the sonar equation (Lee, 1985), an engraulid larval patch with -60 dB average backscattering strength may be shown on the echogram

Table 2. Measured values of instantaneous backscattering strength and instantaneous fish density of each photograph in 1.5–2.5 cm length class

Photograph No.	Density (inds./m³)	SV (dB)	Photograph No.	Density (inds./m³)	SV (dB)
1	528	−79.9	39	1716	−75.8
2	207	−80.6	40	1566	−78.1
3	1472	−78.4	41	6679	−68.2
4	3792	−75.9	42	5245	−71.6
5	3604	−77.0	43	7754	−67.9
6	1472	−75.4	44	9188	−68.1
7	2094	−77.0	45	3811	−71.2
8	3491	−74.0	46	10698	−65.1
9	4037	−75.2	47	12660	−63.3
10	1641	−76.5	48	14226	−63.2
11	736	−78.9	49	11962	−62.2
12	1868	−75.0	50	9887	−65.7
13	2867	−75.7	51	11094	−64.6
14	4585	−74.3	52	4585	−72.8
15	5320	−71.5	53	8924	−65.2
16	5906	−71.3	54	7377	−65.2
17	4981	−74.1	55	6735	−70.3
18	4584	−75.1	56	8452	−67.9
19	5472	−72.1	57	6113	−69.2
20	4792	−71.8	58	6471	−69.1
21	377	−78.3	59	5490	−71.6
22	2754	−70.3	60	9452	−65.4
23	189	−80.6	61	6169	−69.4
24	188	−81.7	62	1491	−74.7
25	226	−80.2	63	170	−79.1
26	1018	−78.6	64	377	−78.3
27	1471	−78.5	65	886	−79.7
28	207	−79.6	66	2019	−76.3
29	5415	−72.9	67	2378	−76.9
30	1924	−74.5	68	3471	−72.7
31	1301	−76.4	69	3981	−72.2
32	1339	−77.9	70	5698	−68.1
33	5792	−73.2	71	5981	−69.5
34	642	−77.1	72	7094	−67.1
35	1981	−78.5	73	7377	−67.7
36	528	−79.7	74	7019	−70.3
37	4585	−72.1	75	7566	−66.2
38	1377	−77.7	76	5962	−68.3

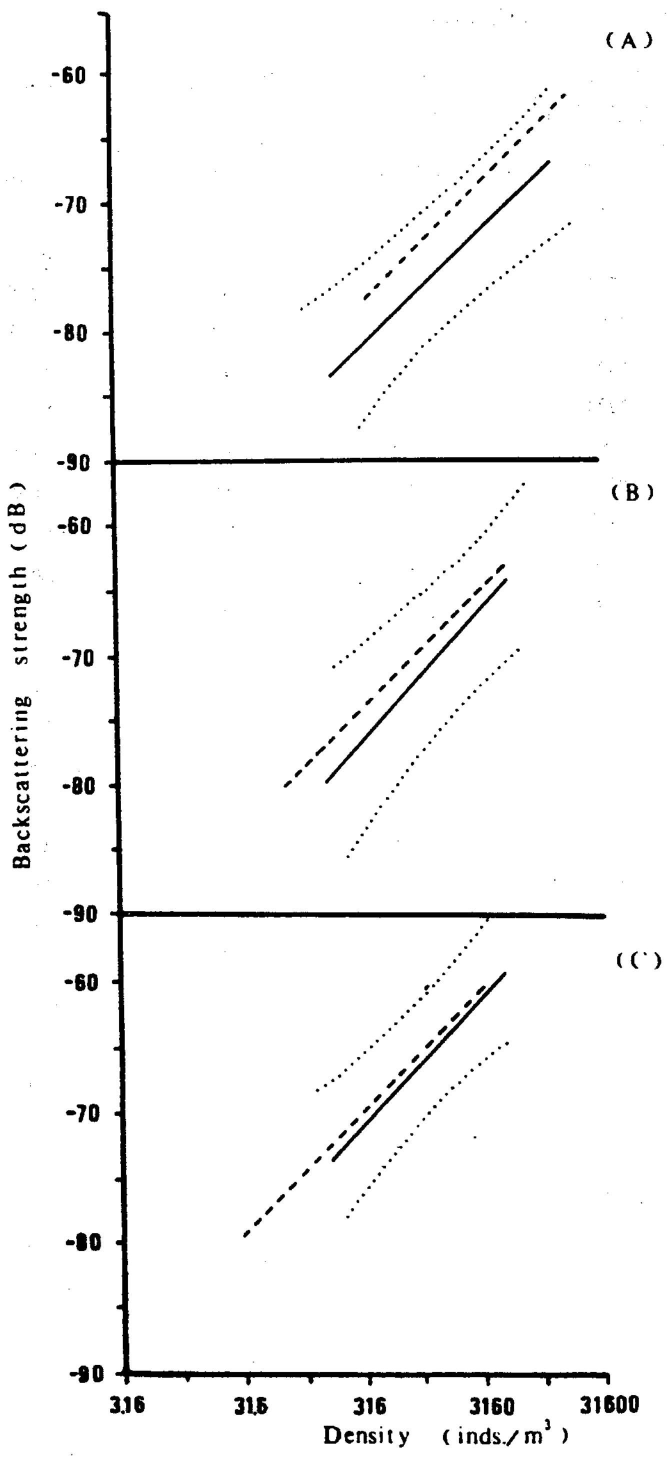

Fig. 8. Comparsion of three regression lines obtained in this experiment. The solid line is the relationship between SV_i and the logarithm of instantaneous school density and the dotted line is the 95% confidence limits of the solid line and the broken line is the relationship between SV and the logarithm of average school density. (A), 1.5-2.5 cm length class; (B), 2.5-3.5 cm length class; (C), 3.5-4.5 cm length class.

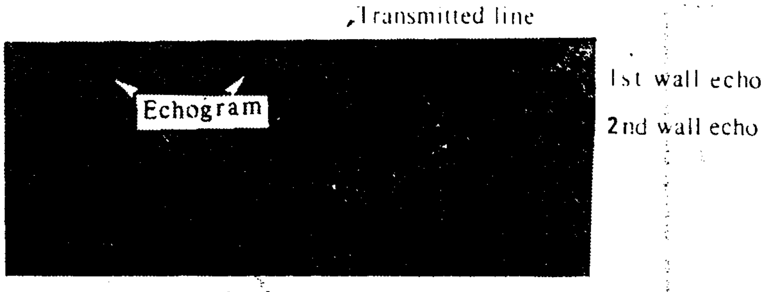

Fig. 9. Echogram of the simulating school.

under the condition of the source level of acoustic system at 120 dB and the depth of the fish school at shallower than 31.6 m from the transducer. In fact, density of the engraulid school indicated on the echogram is very light and is different from that of other species school investigated from coastal waters of Taiwan (Sun, 1988).

The scatters of engraulid school, surveyed by acoustic system at above 80 KHz, was on the geometric scattering zone (Greenlaw, 1977; Maclennan, 1982). In other words, backscattering strength is independant on frequency of acoustic system, but is dependant on density, size and behaviour pattern of the fish. The slopes among three regression lines are not different significantly by means of the F test (Fig. 7; Table 3), but the interceptions among three regression lines are significant difference. Hence, the engraulid larvae described in this experiment were beyond the mechanical resonance phenomenon (Holliday and Pieper, 1980; Lee, 1985). Moreover, the biomass density of an engraulid larval school patch with -70 dB average backscattering strength among three length classes was obtained as 52.5, 71.5 and 102.3 g/m^3 respectively or equivalent to -101.8, -97.4 and -94.1 dB when substituted by the target strength. In other words, the relationship between the average target strength (Ts) and the logarithm of mean body length (BL) is positively linear, and the regression line of $Ts = 26.42 \log(BL) - 110.65$, is obtained from this study, with a correlation coefficient of 0.98 (Fig. 10).

Table 3. F-test for the difference of three regression lines obtained in this experiment

	Σx^2	Σxy	Σy^2	n	b	Residual SS	Residual DF
Regression (A)	718.93	670.95	718.85	20	0.9333	96.675	18
Regression (B)	321.48	305.69	344.53	21	0.9509	53.862	19
Regression (C)	262.49	247.02	270.75	13	0.9411	38.284	11
"Pooled" regression	—	—	—	—	—	184.821	48
"Common" regression	1302.90	1223.66	1334.13	—	0.9392	184.891	50
"Total" regression	1306.45	1224.75	1409.37	54	—	261.209	52

Ho: The three regression lines have the same slope.
Ha: The three regression lines do not have the same slope.
$F=(184.891-184.821)/(3-1)/(184.821/48)=0.00014$
Since $F_{0.05(1),2,48} \doteqdot 3.18$, do not reject *Ho*.
Ho$_1$: The three regression lines have the same interception.
Ha$_1$: The three regression lines do not have the same interception.
$F=(261.209-184.891)/(3-1)/(261.209/50)=7.304$
Since $F_{0.05(1),2,48} \doteqdot 3.18$, reject *Ho*$_1$.

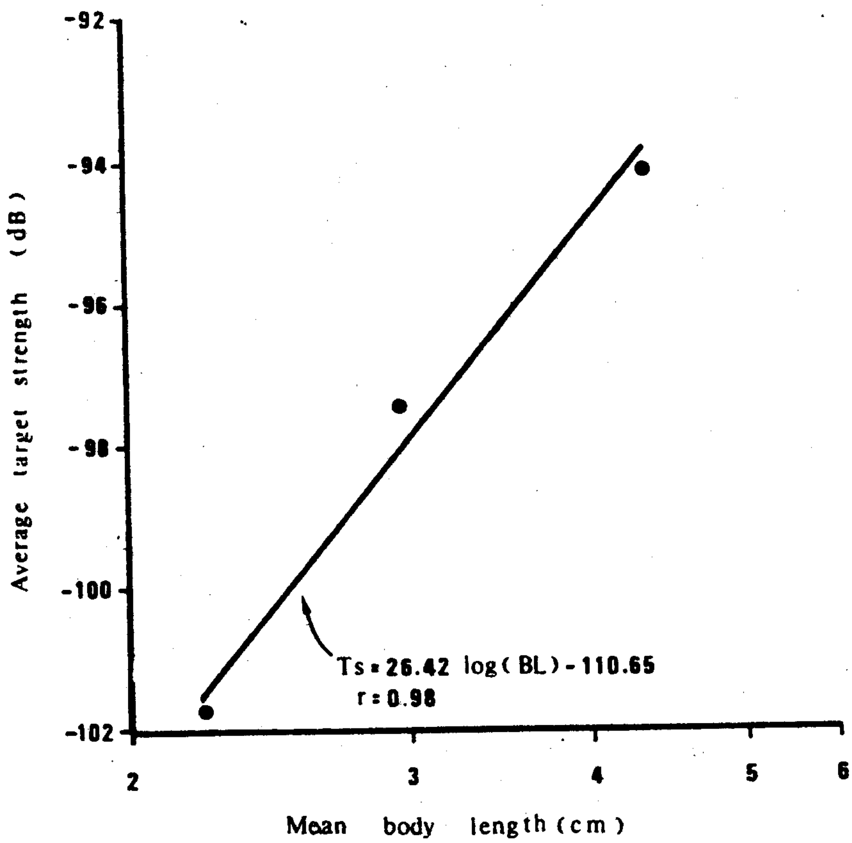

Fig. 10. The relationship between average target strength and the logarithm of body length of engraulid larvae. BL, mean body length

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鯷科仔稚魚密度與超音脈波之後方散亂反射强度之相關性

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通常利用積分方法評估現存量之準確度，有賴於作爲校準因子 (scaling factor) 之後方散亂反射强度 (backscattering strength in dB/m^3) 與魚羣密度（或生體量）對應關係之測定，其測定方法一般有以死魚組成水槽模擬魚羣法及以活魚現場實測法二種。

鯷科仔稚魚體形細小，以死魚組成模擬魚羣有技術上之難點，而活魚之獲得也不可能，故本實驗是透過篩具，將不同重量的鯷科仔魚羣均勻灑落在水中，利用水中照像機拍攝魚羣密度，並將拍攝瞬間的魚羣反射信號檢出，予以數值化處理，求取魚羣密度與平均後方散亂反射强度之關係，以作爲將來從事鯷科仔魚現存量評估時的校準因子之用。其結果如下：

(1) 鯷科仔魚羣密度超過 1000 g/m^3 時，魚羣反射信號不再隨著密度之增加而增加。

(2) 在界線密度之下，不同體長區間，魚羣之後方散亂反射强度與魚羣密度呈一良好之直線關係，故利用超音波評估鯷科仔稚魚之現存量是可行的。

(3) 鯷科仔稚魚之單體反射强度極爲微弱，約在 −101.8 dB～−94.1 dB 之間，故其魚探記錄跡極淡。