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Studies on Acoustic Target Strength of Squid
II. Effect of behaviour on averaged dorsal aspect target strength

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Abstract

The effect of behaviour on dorsal aspect target strength is simulated through computation of the average target strength with respect to normal orientation distribution (joint tilt-toll angle and single tilt angle distributions) of squid in the sound beam. The basic data consist of measurements of the dependence of joint tilt-roll angle on the target strength function of dead and tethered squid. Average target strengths are regressed on the logarithm of dorsal mantle length of squid. Several statistical tests are performed to determine the similarity of regressions for two squid species (*Todarodes pacificus* and *Ommastrephes bartrami*), two ensonifying frequencies (50 kHz and 200 kHz), and two measuring methods (intensity and energy domains).

From this study it can be summarized that: (1) For a soft-bodied marine organism such as squid, measurement of dorsal aspect target strength with respect to joint tilt-roll angle distributions is considered more realistic and accurate than that of single tilt angle distribution only because of the sensitivity of this "bladderless fish" to the orientation or aspect. (2) There is a significant effect of behaviour on averaged dorsal aspect target strength of squid. Thus, in order to facilitate accurate abundance estimation of squid acoustically, the need for measurements of the behaviour or the orientation distribution of ensonified squid is emphasized. (3) Other than behaviour, systematic size, species, and ensonifying frequency are among the prominent factors which determine values and characteristics of the squid target strength. Furthermore, for future measurements, the effect of the acoustic impedance (density and sound speed) differences between squid body and surrounding medium, and the uniqueness of swimming behaviour must be considered.

Introduction

The target strength of fish and other marine organisms is a prime factor to consider when designing echo sounders and for quantitative and qualitative assessment of their stocks by acoustic means. Prominent factors which determine values and characteristics of the fish target strength are body length, shape, species, ensonifying frequency, orientation and behaviour, structural components of the body and their physical properties (especially density and sound speed), as well as condition factors including reproductive state, stomach and fat content, and anything else that affects the sound reflecting properties of fish. Among these factors, orientation and behaviour have received the most attention.

Theoretical and empirical studies indicate that the echo returned from a group

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of fish is influenced by their behaviour[1]. The measurement most indicative of the contribution of an individual fish to the total echo is the mean backscattering cross section or target strength of a fish of the same species and similar length. This mean is the average of target strength with respect to the joint probability distribution function of spatial and orientation states when weighted by the transmission and receiver beam patterns of the echo sounder in use. In many situations the spatial and orientation states of a fish are different. In these cases, the orientation distribution may be considered as a combination of purely physical properties of the fish and their behaviour. Thus, by averaging the target strength with respect to the orientation distribution states of the fish, the effect of behaviour on averaged target strength may be studied.

In this paper, the dependence of the averaged dorsal aspect target strength on the orientation distribution or behaviour of the squid is examined. The effect of behaviour on dorsal aspect target strength is simulated through computation of the average target strength with respect to normal orientation distributions. For squid, which are soft-bodied, the behaviour can be characterized by the joint tilt-roll angle distribution, not the tilt angle distribution alone. After reviewing the target strength function with respect to the joint tilt-roll angle distribution, a method of averaging the target strength function is obtained. This is then applied to the measured dorsal aspect target strength functions of two species of squid at two ensonifying frequencies, which are then averaged with respect to several observed and postulated orientation distributions. The computed averaged target strengths are regressed on the logarithm of squid dorsal mantle length. The basic data consists of measurements of joint tilt-roll angle dependence of target strength of dead and tethered squids.

Materials and Methods

1. *Materials*

The squid used were surume ika (*Todarodes pacificus*), and aka ika (*Ommastrephes bartrami*). All dorsal mantle lengths and body weights are listed in Table 1. Since, however, squids were frozen at capture and thawed out immediately prior to measurement, it was necessary to allow them to stabilize in the water tank. Before ensonification, they were checked for bubbles forming in the body: if present such bubbles were removed by manipulation of the body to allow the gas to escape.

2. *Experimental set-up*

As reported in the previous paper[2], the block diagram of the instrumentation and the arrangement of the apparatus are shown in Fig. 1. The measurements were performed in a large water tank of 108 m^3 capacity (12-m length $\times$ 3-m width $\times$ 3-m depth). One set of transducers with frequencies of 50 kHz and 200 kHz, pulse lengths of 0.5 and 0.2 ms, and half-beam widths of 16.5 and 8° were used both as projector and receiver. Calibration of the echo sounder (JRC-JFV-216) was performed by means of a 91 mm standard steel ball. The echo signals received by the echo sounder were processed by a FFT Analyzer (ONO SOKKI CF-920) and monitored by Oscilloscope. Input to this FFT Analyzer consisted of echo signals sampled along a display time scale of 8 ms, with sampling interval of 0.0076 ms, averaged

Table 1. Basic biology of the 30 squid specimens.

Squid No.	Species	Dorsal *ML* (cm)	Weight (g)	Squid No.	Species	Dorsal *ML* (cm)	Weight (g)
01	Surume	15.0	60	16	A k a	15.2	103
02	〃	16.6	90	17	〃	16.2	104
03	〃	17.2	100	18	〃	16.4	88
04	〃	18.4	175	19	〃	17.2	133
05	〃	19.0	133	20	〃	17.4	167
06	〃	22.0	250	21	〃	17.5	138
07	〃	22.5	285	22	〃	18.4	176
08	〃	22.8	260	23	〃	23.0	405
09	〃	25.0	305	24	〃	23.5	385
10	〃	25.0	308	25	〃	23.8	377
11	〃	26.0	410	26	〃	24.2	422
12	〃	26.4	447	27	〃	26.0	540
13	〃	27.8	472	28	〃	26.6	527
14	〃	28.6	560	29	〃	27.5	557
15	〃	29.2	560	30	〃	28.1	677

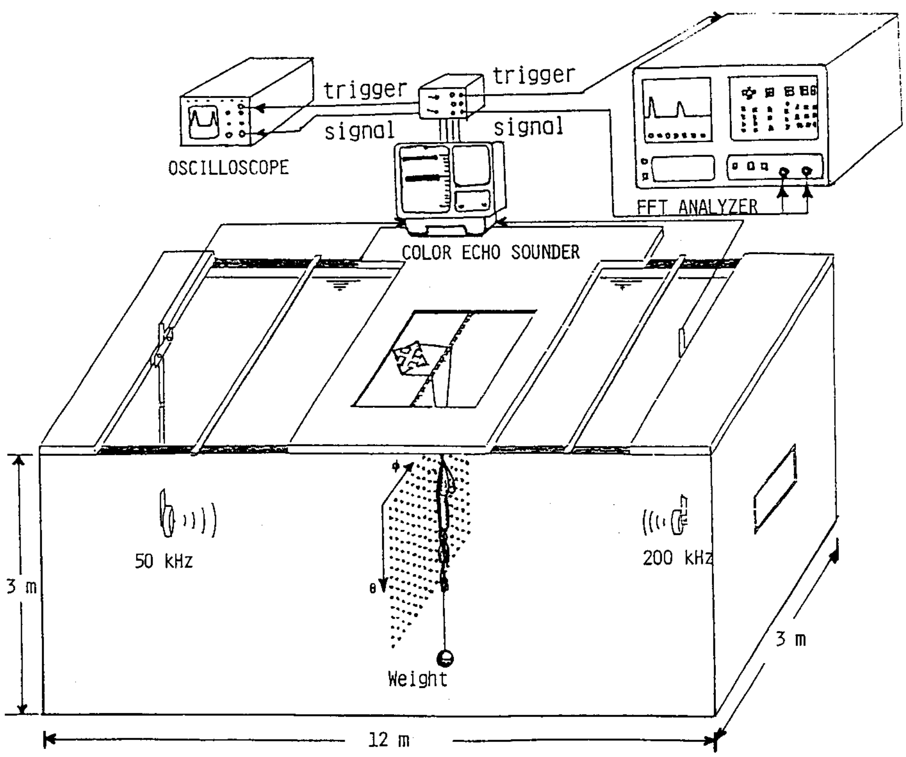

Fig. 1. Experimental set-up and block diagram of measuring system.

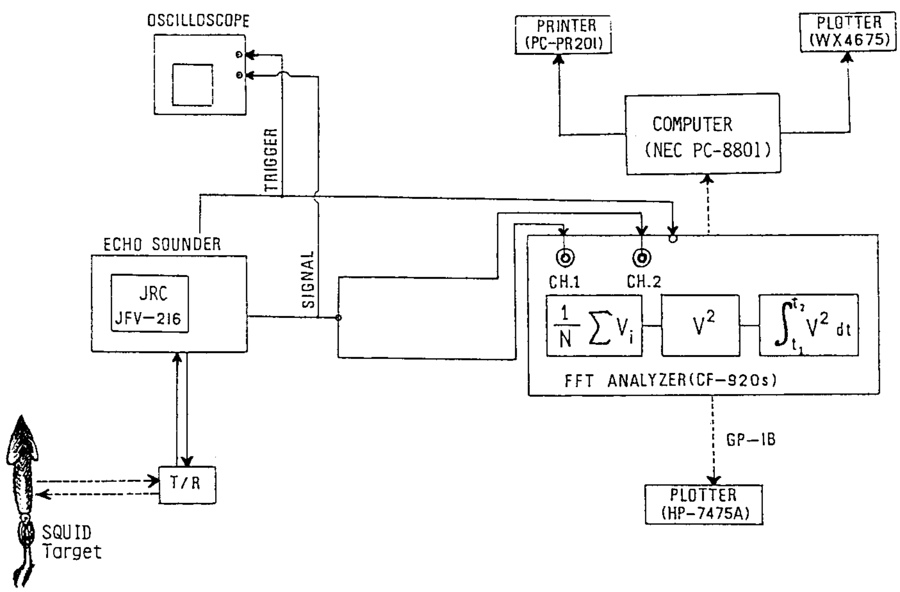

Fig. 2. Apparatus of data acquisition and processing system.

(running average) for 16 runs. The block diagram of the data acquisition and processing system is shown in Fig. 2, and details of the basic methods for acquiring intensity and energy target strength values were reported before[2].

Most dorsal aspect target strength measurements of fish have been conducted with tilt angle as a significant orientation indicator in the sound beam[1]. It is considered that as an excellent approximation in application of a vertical echo sounder, the orientation can be represented entirely by the tilt angle[3]. The tilt angle is defined as the angle made by the imaginary center line, running from the root of the tail to the tip of the upper jaw, and the horizontal line. For squid, tilt angle may be defined as the angle made by the center line, extending from the root of the tailfin to the center of the eye, excluding the uncertain configuration form of the arms and tentacles. The sign convention is that positive angles denote head-up orientaion; negative angles, head-down orientations. Furthermore, for squid, which are soft-bodied marine organisms with easily changeable body shape during orientation in the sound beam, the spatial orientation-based measurement is considered to be accurate. Consequently, dorsal aspect target strengths must be measured as a function of the joint tilt-roll angle distribution.

Since the basic measurements of target strengths were relative to the reference target (standard steel ball), the spatial orientation-based measuring method was first applied to measure echo intensity and echo energy of the reference target before determining echo intensities and echo energies of squids.

The measurements were obtained by manually moving targets through the sound beam at 1.7° intervals along a ±10.2° scan in one (x-axis) direction, spaced at the same ±10.2° intervals in the perpendicular (y-axis) direction, for 50 kHz; and at 1.2° intervals along a ±8.6° scan in the x-axis direction, spaced at ±8.6° intervals in the y-axis direction, for 200 kHz. Those sections from which data were collected were restricted to $\pm 10.2^{\circ}$ angle of each axis for 50 kHz because of the limiting size of water tank; and to $\pm 8.6^{\circ}$ angle for 200 kHz because of the narrow beam width of the transducer used in the experiments.

3. *Data analysis*

In its general form, the averaged backscattering cross section $\langle\sigma\rangle$ can be expressed by integrating the triple product of cumulative gain (G), product of transmitted and received beam pattern b^2, and backscattering cross section σ over the continuum of possible observation states[4]:

$$\langle\sigma\rangle = \int Gb^2\sigma dF \Big/ \int Gb^2 dF, \tag{1}$$

where dF is the probability element associated with squid position and orientation. The integral of Gb^2 over the same distribution of the observation states provides normalization convenient for the purpose of comparing measurements of echo strengths of squid of disparate size, species, ensonifying frequency, physical condition, and behaviour as assumed implicitly in the choice of orientation distribution in averaging.

In order to gain some insight into the actual computation of $\langle\sigma\rangle$, Equation (1) is now simplified for the example case of ensonification of squid of perturbed behaviour by an echo sounder with application of "40 log r" TVG to the received signal. Thus, the averaged backscattering becomes:

$$\langle\sigma\rangle = \iint b^2(k)\sigma(k, K)dF(K)dF(k) \Big/ \int b^2(k)dF(k), \tag{2}$$

where the squid direction k is a function of angular position of the target in the sound beam, and orientation K is a function of tilt and roll angle of the target, $f(\theta, \phi)$. According to the Equation (2), the combined transmitted-received beam pattern b^2 must be involved in computation $\langle\sigma\rangle$. However, for simplification of computation, effect of beam pattern is considered negligible, the transducer is modelled as an ideal circular piston, the spatial distribution is assumed to be uniform, and the distribution of orientation states is assumed to be normal, independent of relative azimuthal orientation.

Consequently, the average backscattering cross section is computed merely with respect to joint tilt-roll angle distribution by the simple form:

$$\langle\sigma\rangle = \iint \sigma(\theta, \phi)f(\theta, \phi)d\phi d\theta \Big/ \iint f(\theta, \phi)d\phi d\theta, \tag{3}$$

where $\sigma(\theta,\phi)$ is the relative backscattering cross section of squid at tilt angle θ and roll angle ϕ, computed by

$$\sigma(\theta, \phi) = 4\pi 10^{TS(\theta,\phi)/10}, \tag{4}$$

and $f(\theta, \phi)$ is the truncated bivariate (joint) probability density function of tilt-roll angle distribution assumed normal over the integration range $[(\bar{\theta}-3s_\theta, \bar{\theta}+3s_\theta)$ and $(\bar{\phi}-3s_\phi, \bar{\phi}+3s_\phi)]$ and vanishing otherwise. And

$$f(\theta,\ \phi)=\begin{cases}\dfrac{1}{2\pi s_\theta s_\phi\sqrt{1-\gamma^2}}\exp\left\{-\dfrac{1}{2(1-\gamma^2)}\left[\left(\dfrac{\theta-\bar{\theta}}{s_\theta}\right)^2\right.\right. \\ \qquad\left.\left.-2\left(\dfrac{\theta-\bar{\theta}}{s_\theta}\right)\left(\dfrac{\phi-\bar{\phi}}{s_\phi}\right)+\left(\dfrac{\phi-\bar{\phi}}{s_\phi}\right)^2\right]\right\}, \\ \qquad \text{for } |\theta-\bar{\theta}|\leqq\lambda s_\theta, \text{ and } |\phi-\bar{\phi}|\leqq\lambda s_\phi\,; \\ 0, \text{ for } |\theta-\bar{\theta}|>\lambda s_\theta, \text{ and } |\phi-\bar{\phi}|>\lambda s_\phi.\end{cases} \tag{5}$$

where γ is the correlation coefficient between tilt angle θ and roll angle ϕ, $\bar{\theta}$ and $\bar{\phi}$ are the mean tilt and roll angles, s_θ and s_ϕ are the standard deviation of the tilt and roll angle distributions, and λ is a factor equal to three. Then, for easy calculability and simplification, it is assumed that the correlation coefficient γ is equal to 0, and the mean and standard deviation of tilt angle are equal to the mean and standard deviation of roll angle.

To demonstrate the power of the above averaging model, averaging with respect to the tilt angle distribution only is also performed. As in NAKKEN and OLSEN[3] and FOOTE[4], it is assumed that the backscattering cross section is insensitive with respect to the roll angle. Consequently, the average backscattering cross section is

$$\langle\sigma\rangle=\int\sigma(\theta)f(\theta)d\theta\ /\ \int f(\theta)d\theta, \tag{6}$$

where $f(\theta)$ is the truncated univariate (single) probability density function of tilt angle θ, assumed to be normal over the integration range $[\bar{\theta}-3s_\theta,\ \bar{\theta}+3s_\theta]$ and vanishing otherwise:

$$f(\theta)=\begin{cases}\dfrac{1}{s_\theta\sqrt{2\pi}}\exp\left[-(\theta-\bar{\theta})/2s_\theta^2\right], \text{ for } |\theta-\bar{\theta}|\leqq\lambda s_\theta\,; \\ 0, \text{ for } |\theta-\bar{\theta}|>\lambda s_\theta.\end{cases} \tag{7}$$

where λ is a factor equal to three. Use of this distribution was motivated by our observation of tilt angle distribution of squid (surume ika) in the aquarium with mean of -4.0 deg and standard deviation of 11.1 deg. A histogram of the 471 data is shown in Fig. 3, and photograph of schooling squid is shown in Figure 4.

The average backscattering cross section is computed for each measured target strength function for each value of the paired parameters of behaviour as shown in Table 2. The corresponding average target strengths, defined by direct substitution of $\langle\sigma\rangle$ in Equation (3) and (6) for $\langle\sigma\rangle$ in the following Equation,

$$\langle TS\rangle=10\log\langle\sigma\rangle/4\pi, \tag{8}$$

are regressed on dorsal mantle length ML (in centimeters) according to each of two equations,

$$\langle TS\rangle=m\log ML+b \tag{9}$$

and

$$\langle TS\rangle=20\log ML+b'. \tag{10}$$

Both analysis are performed according to the usual least-mean-squares analysis. Equation (10) is used to facilitate the systematic comparison of the two species of squid measured, two ensonifying frequencies, two measuring methods (intensity and energy domains), and two averaging models of target strength. Significance in these comparisons is conducted by the two-way analysis of variance[5].

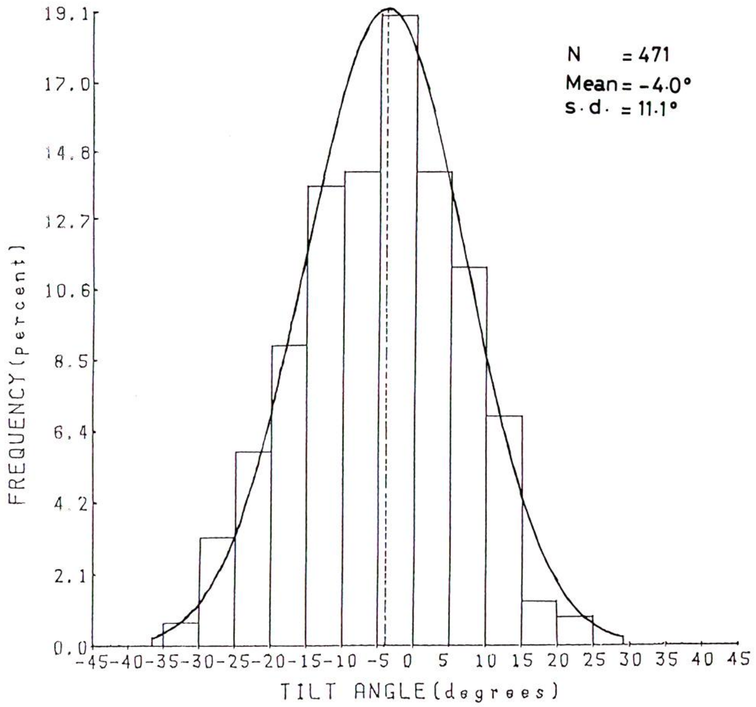

Fig. 3. Distribution of squid tilt angle measured relative to the horizontal plane (evening photographs).

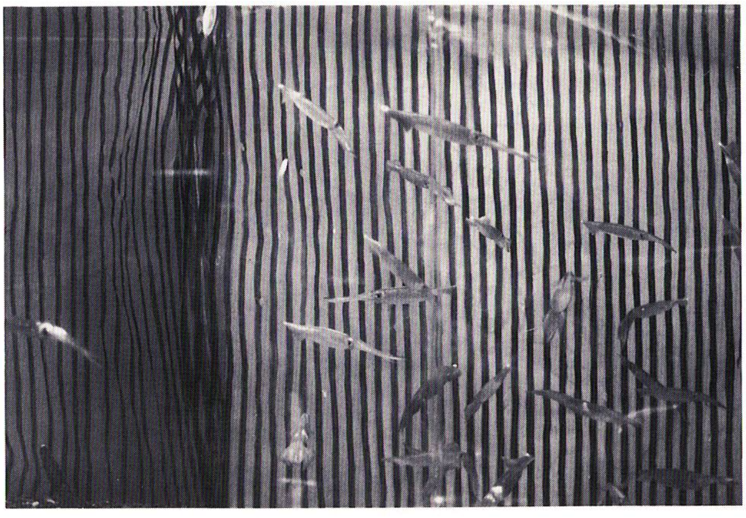

Fig. 4. A sample of photographic print showing schooling squid in the aquarium.

Table 2. Parameters of joint tilt-roll angle distributions and single tilt angle distributions used for calculation of average backscattering cross section.

Mean (deg.)	Standard deviation (deg.)	Assuming behaviour	Symbol of behaviour mode
0	(10.2, 10.2)	Mean horizontal	N (0, 10.2, 10.2)
0	(8.6, 8.6)	〃	N (0, 8.6, 8.6)
0	10.2	〃	N (0, 10.2)
0	8.6	〃	N (0, 8.6)
−4	11.1	Slightly downward looking orientation	N (−4, 11)

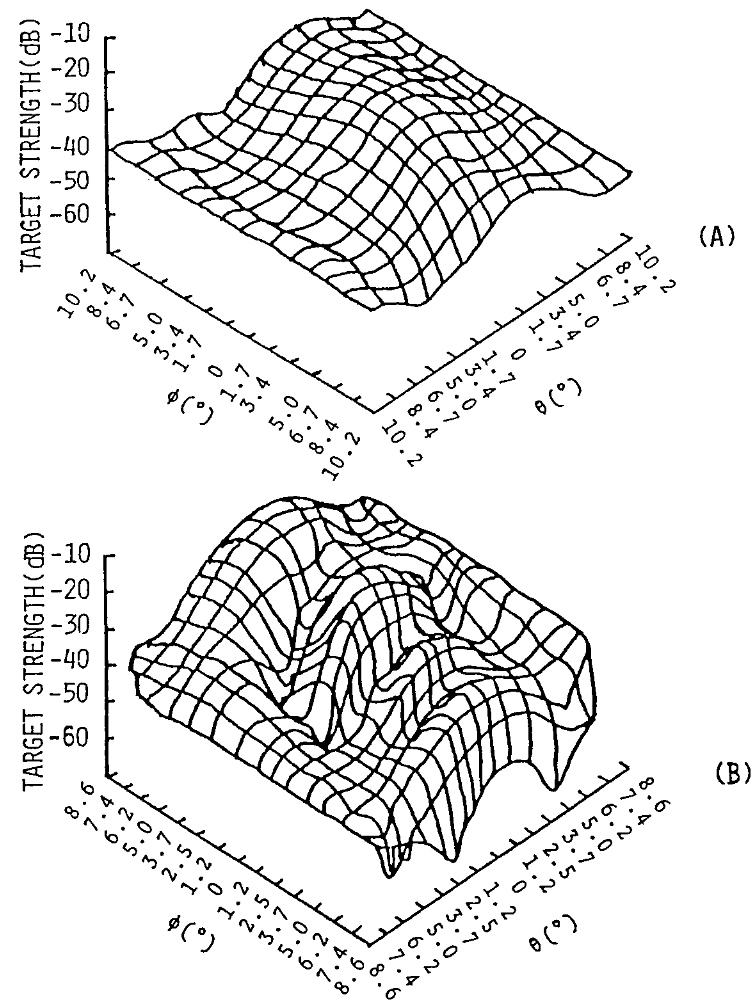

Fig. 5. Dorsal aspect target strength functions with respect to joint tilt-roll angle measurement of 17.2 cm surume ika at 50 kHz(A) and 200 kHz(B).

Results and Discussion

1. Target strength function

Compared with target strength functions in the roll plane[2], target strength functions with respect to joint tilt-roll angle measurement are more complicated and fluctuating. As in roll plane target strength function, these fluctuations were related closely on ensonifying frequency and squid size. Target strength function at 200 kHz is more fluctuating than that at 50 kHz, as shown in Fig. 5 and Fig. 6 for surume ika and aka ika, respectively. The target strength contours were not representated by parabolas form, thus it was very difficult to smooth the estimated

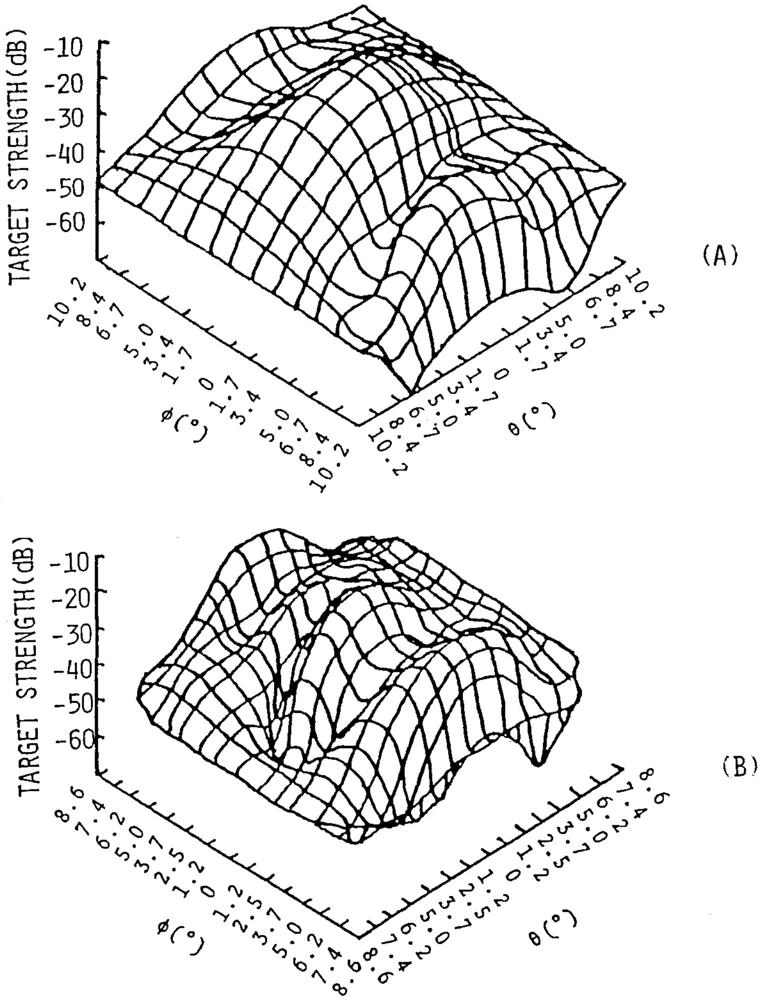

Fig. 6. Dorsal aspect target strength function with respect to joint tilt-roll angle measurement of 17.2 cm aka ika at 50 kHz(A) and 200 kHz(B).

values when it was necessary to do so.

However, in general, maximum target strength values were determined at or near zero joint tilt-roll angle position. It is considered that squid is like mackerel, which lacks a swimbladder ("bladderless fish"), consequently backscattering cross section or target strength are approximately balanced about the horizontal[6].

Another reason for the high fluctuation of target strength value, may be that the complete measurement procedure is time consuming. Echo sounder sensitivity drift or slight variation in the resonance frequency of the transducer during measurement is possibly the source of random error or the error due to imprecision. The slight shifts in the suspension apparatus attached to the squid may also be a source of this error. However, the error caused by moving the squid target during measurement was minimized by reading the received echo signal when the squid target was fixed in corresponding positions.

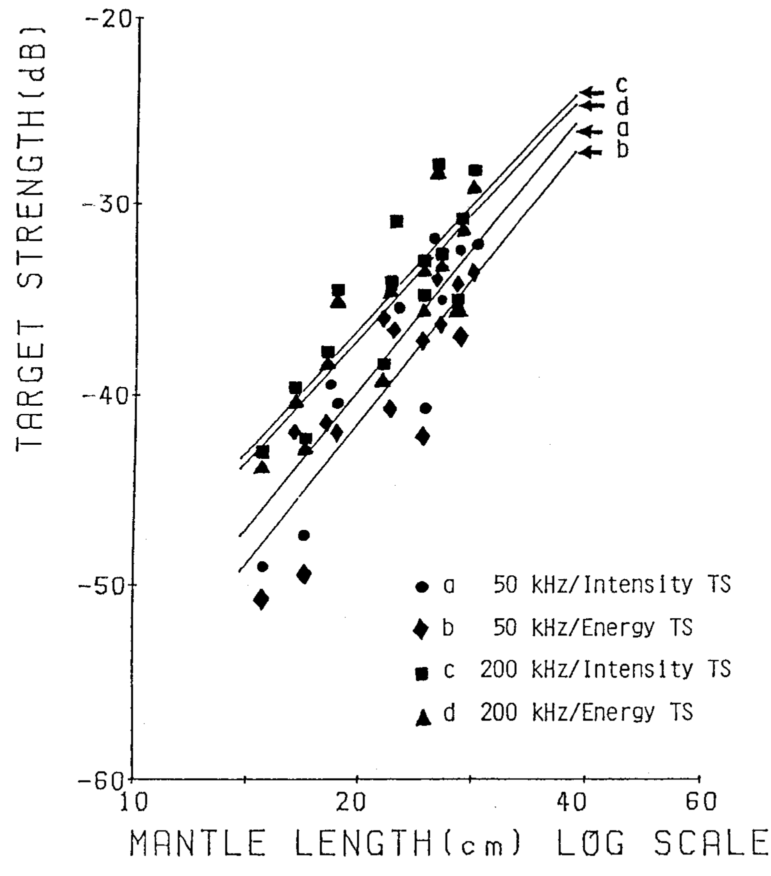

Fig. 7. Scatter diagram and regression of averaged dorsal aspect target strength of surume ika at 50 kHz and 200 kHz.

a. $TS = 47.50 \log ML - 101.90$ ($r = 0.840$)
b. $TS = 48.23 \log ML - 104.58$ ($r = 0.850$)
c. $TS = 41.98 \log ML - 91.48$ ($r = 0.840$)
d. $TS = 42.02 \log ML - 92.05$ ($r = 0.837$)

Because of the high fluctuation of target strength value as described above, the necessity of averaging the target strength functions of squid and of basing target strength to length regressions on these averages in now apparent. It is now recognized that using target strength-length relationships that are not averaged for appropriate orientation distribution or behaviour of squid can result in large errors in estimates of acoustic abundance.

2. Effect of behaviour on averaged dorsal aspect target strengths

The measured dorsal aspect target strength functions of 30 squid at two ensonifying frequencies and two measuring methods have been averaged in accordance with the procedure outlined above for each of three different kinds of behaviour. In the first and second case, the averaging was performed with repect to the postulated tilt angle and roll angle distributions with pairs of parameters (0, 10.2) and (0, 8.6) degrees for 50 kHz and 200 kHz, respectively. And in the third case, the averaging

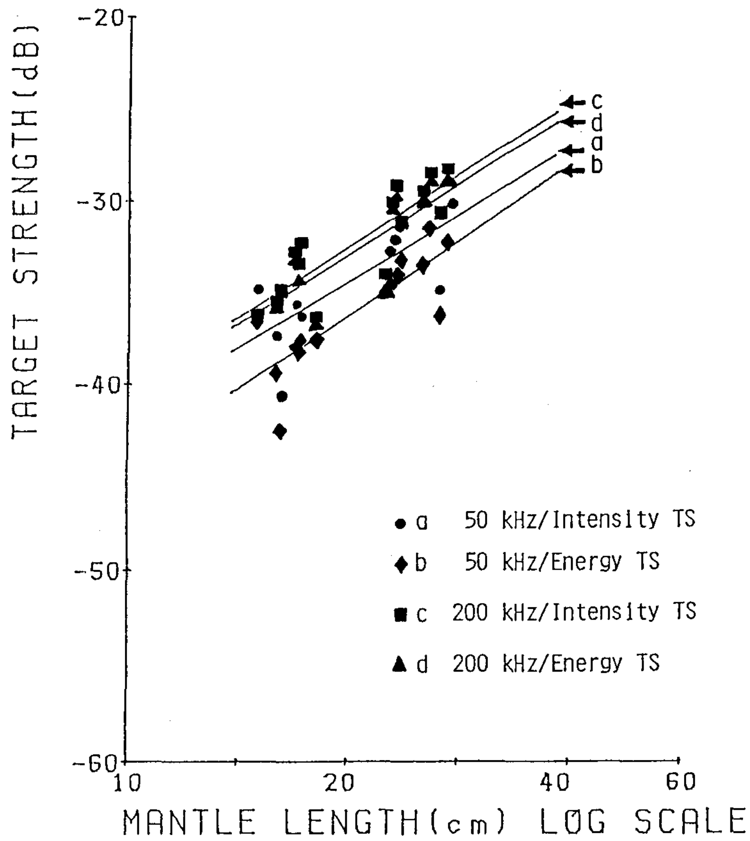

Fig. 8. Scatter diagram and regression of averaged dorsal aspect target strength of aka ika at 50 kHz and 200 kHz.

a. $TS=23.35 \log ML-64.96$ ($r=0.770$)
b. $TS=26.17 \log ML-70.47$ ($r=0.820$)
c. $TS=24.73 \log ML-64.83$ ($r=0.853$)
d. $TS=23.23 \log ML-65.60$ ($r=0.843$)

was performed with respect to the actual/measured tilt angle distribution with pairs of parameters (−4, 11).

In Figs. 7 and 8, results of averaging the 15 target strength functions of surume ika and aka ika, respectively, are presented in the form of a scatter diagram of averaged target strengths with respect to joint tilt-roll angle distribution arranged against squid dorsal mantle length. There the orientation distribution underlying the averaging operation is defined symbolically, assigning the tilt-toll angle N(0, 10.2, 10.2) for 50 kHz and N(0, 8.6, 8.6) for 200 kHz, by which the above essentially normal distribution in joint tilt-roll angle is understood. The least mean squares regression of the averaged target strengths are shown together with its source data in the same figures. The complete results of these regression analysis for the two squid species, two measuring methods and two ensonifying frequencies are summarized in Table 3. The quality of regression may be judged from the correlation coefficient r which has fairly high values.

From these figures and the table, it is seen that the value of energy target strength is smaller than intensity target strength as was expected[2]. And in general, the value of averaged target strength of aka ika is larger than the value of surume ika. This may be caused by differences in the physical composition or rigidity of the body. It is well known that the mantle of aka ika is more rigid and thick that of surume ika.

The corresponding scatter diagrams, together with least mean squares regressions for averaged target strengths with respect merely to measured and postulated tilt angle distributions, are presented in Fig. 9 and Fig. 10 for surume ika and aka ika, respectively. The complete results of the regression analysis are summarized in Table 4.

Because of apparent heterogenity of variance or standard deviation among each set of regressions as shown above, Equation (10) was used to facilitate the comparison. The similarity in condition factors for surume ika and aka ika support the comparison of the target strengths ; both squid are of the approximately same dorsal mantle length. All of the comparisons (by the two-way analysis of variance) are in

Table 3. Summary of regression analysis of averaged dorsal aspect target strength of squid on dorsal mantle length for averaging with respect to normal joint tilt-roll angle distribution for two squid species at two ensonifying frequencies.

Species	Freq. (kHz)	Measur. methods	Averaging models	Slope		Intercept		Lin. cor.
				m	$s.d.$	b	$s.d.$	r
Surume	50	I*)	N (0, 10.2, 10.2)	47.50	7.95	−101.90	10.75	0.840
		E**)	N (0, 10.2, 10.2)	48.23	7.73	−104.58	10.45	0.850
	200	I	N (0, 8.6, 8.6)	41.98	6.90	− 91.48	9.32	0.840
		E	N (0, 8.6, 8.6)	42.02	7.08	− 92.05	9.56	0.837
Aka	50	I	N (0, 10.2, 10.2)	23.35	4.96	− 64.96	6.65	0.770
		E	N (0, 10.2, 10.2)	26.17	4.69	− 70.47	6.22	0.820
	200	I	N (0, 8.6, 8.6)	24.73	3.90	− 64.83	5.17	0.853
		E	N (0, 8.6, 8.6)	24.23	3.99	− 64.60	5.29	0.843

*) I is intensity domain,
**) E is energy domain

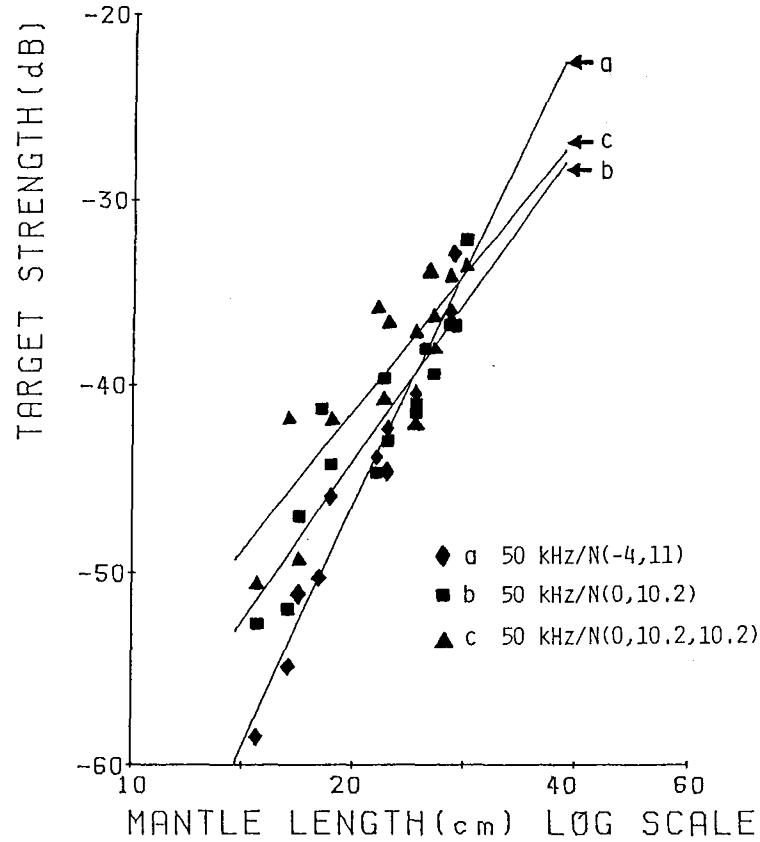

Fig. 9. Scatter diagram and regression of averaged dorsal aspect target strength of surume ika at 50 kHz.
a. $TS = 81.88 \log ML - 153.70$ ($r = 0.980$)
b. $TS = 55.26 \log ML - 116.48$ ($r = 0.908$)
c. $TS = 48.23 \log ML - 104.58$ ($r = 0.850$)

terms of the regression coefficient or intercept b'. The value of the corresponding coefficient for each species, ensonifying frequencies, measuring methods, and averaging models are summarized in Table 5.

Results of these comparisons are: (1) there is a significant difference in averaged dorsal aspect target strength between the two measuring methods (intensity and energy domains); (2) there are significant differences between the two measured squid species; and (3) differences in behaviour modes or orientation distribution of squid significantly affect the regression of averaged dorsal aspect target strength.

From these results of averaged dorsal aspect target strength-to-dorsal mantle length regression, it is considered that only with respect to different behaviour modes or orientation distributions weighted on averaging models, averaged target strengths would be different. This does not mean, however, that the quality of predictions of squid abundance necessarily will be materially affected by the choice of regression, or, equivalently, by the assumption of behaviour or associated orientation distribu-

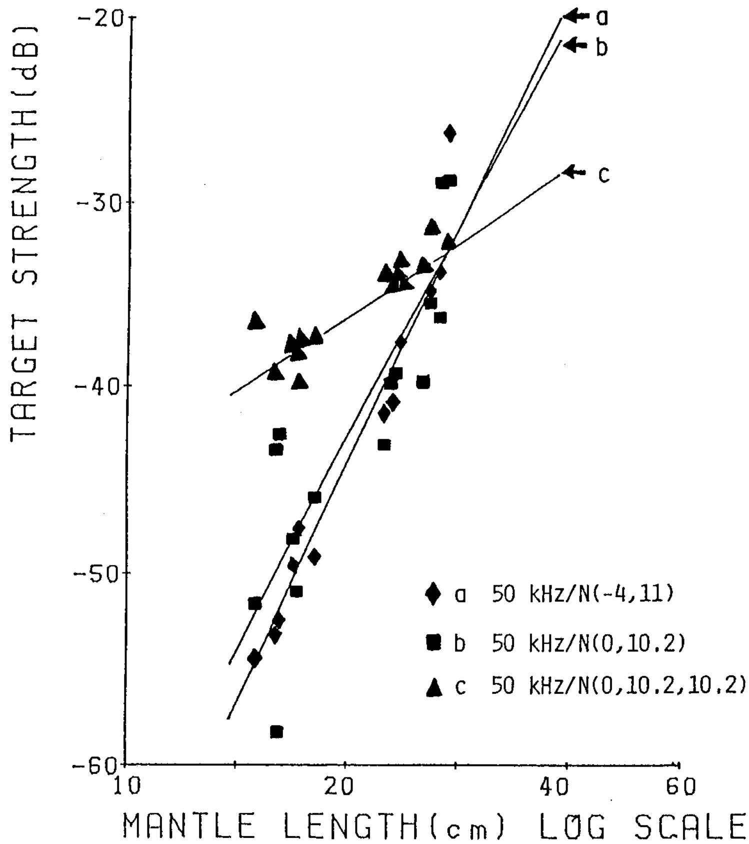

Fig. 10. Scatter diagram and regression of averaged dorsal aspect target strength of aka ika at 50 kHz.
a. $TS = 82.42 \log ML - 152.08$ ($r = 0.959$)
b. $TS = 73.30 \log ML - 138.69$ ($r = 0.843$)
c. $TS = 26.17 \log ML - 70.47$ ($r = 0.820$)

tion. Therefore, simple linear regression analysis of the derived target strength data according to these behaviour modes, ensonifying frequency, species, size, and other parameters is considered to be acceptable.

It is important to note here that because the measurements were conducted in fresh water, the values of average target strength were much higher than the average target strength values obtained from in situ measurement[7]. The theoretical study[8] indicated that for fish and other marine organisms which lack a swimbladder ("bladderless fish"), density and sound speed (acoustic impedance) differences in the scattering from liquid body may cause variations of 5-15 dB in the target strength. Thus, in subsequent studies, measurement will be performed in sea water because of the significant sensitivity of "bladderless fish" target strength on surrounding medium and other factors. Also, the difference of 20 degrees of the slope m in regression line of averaged dorsal aspect target strength-to-dorsal mantle length for bladder fish[9,10], pointed out the dissimilarity of those two-groups of "fish". Addi-

Table 4. Summary of regression analysis of averaged dorsal aspect target strength of squid on dorsal mantle length for averaging with respect to normal tilt-angle distribution for two squid species at two ensonifying frequencies.

Species	Freq. (kHz)	Measur. methods	Averaging models	Slope		Intercept		Lin. cor.
				m	*s.d.*	*b*	*s.d.*	*r*
Surume	50	I*)	N (−4, 11)	81.91	4.55	−152.06	6.14	0.977
		E**)	N (−4, 11)	81.88	4.22	−153.70	5.71	0.980
		I	N (0, 10.2)	51.48	5.88	−109.92	7.94	0.914
		E	N (0, 10.2)	55.26	6.58	−116.48	8.88	0.908
	200	I	N (0, 8.6)	58.73	5.49	−114.23	7.42	0.940
		E	N (0, 8.6)	59.66	5.51	−115.78	7.44	0.940
A k a	50	I	N (−4, 11)	79.72	6.37	−147.15	8.44	0.950
		E	N (−4, 11)	82.42	6.25	−152.08	8.28	0.959
		I	N (0, 10.2)	72.04	12.05	−135.52	15.90	0.839
		E	N (0, 10.2)	73.30	12.04	−138.69	15.90	0.843
	20	I	N (0, 8.6)	42.04	7.61	− 88.56	10.10	0.818
		E	N (0, 8.6)	43.24	7.29	−90.77	9.65	0.837

*) I is intensity domain,
**) E is energy domain

Table 5. Intercept or regression coefficient b' together with the correlation coefficient r, computed on the bases of the measured target strength functions for some averaging models.

Species	Freq. (kHz)	Measuring methods	Averaging models	Regression coefficient b'	Linear correl. r
Surume	50	I*)	N (0, 10.2, 10.2)	−64.83	0.840
		E**)	N (0, 10.2, 10.2)	−66.52	0.850
		I	N (−4, 11)	−68.61	0.977
		E	N (−4, 11)	−70.29	0.980
		I	N (0, 10.2)	−67.49	0.914
		E	N (0, 10.2)	−68.94	0.908
	200	I	N (0, 8.6, 8.6)	−61.85	0.840
		E	N (0, 8.6, 8.6)	−62.36	0.837
		I	N (0, 8.6)	−62.03	0.940
		E	N (0, 8.6)	−62.32	0.940
A k a	50	I	N (0, 10.2, 10.2)	−60.54	0.770
		E	N (0, 10.2, 10.2)	−62.31	0.820
		I	N (−4, 11)	−68.28	0.950
		E	N (−4, 11)	−69.64	0.959
		I	N (0, 10.2)	−66.79	0.839
		E	N (0, 10.2)	−68.30	0.843
	200	I	N (0, 8.6, 8.6)	−58.57	0.853
		E	N (0, 8.6, 8.6)	−59.02	0.845
		I	N (0, 8.6)	−59.45	0.818
		E	N (0, 8.6)	−60.07	0.837

*) I is intensity domain,
**) E is energy domain

tional studies will be directed at describing this phenomenon either theoretically or empirically.

Conclusions

The effect of behaviour on dorsal aspect target strength of squid was simulated through computation of the average target strength with respect to normal orientation distribution (joint tilt-roll angle and single tilt angle distributions) of squid in the sound beam. The basic data consisted of measurements of the joint tilt-roll angle dependence on target strength function for dead and tethered squid. Average target strengths were regressed on the logarithm of dorsal mantle length of squid. Several statistical tests were performed to determine the similarity of regressions for two squid species, *i.e.*, surume ika and aka ika, two ensonifying frequencies (50 kHz and 200 kHz), and two measuring methods (intensity and energy domains).

The results of this study can be summarized as follows:

(1) For a soft-bodied marine organism such as squid, measurement of dorsal aspect target strength with respect to joint tilt-roll angle distributions is considered more realistic and accurate than that of single tilt angle distribution only because of the sensitivity of this "bladderless fish" to the orientation or aspect.

(2) There is a significant effect of behaviour on averaged dorsal aspect target strength of squid. Thus, in order to facilitate accurate abundance estimation of squid acoustically, the need for measurements of the behaviour or the orientation distribution of ensonified squid is emphasized.

(3) Other than behaviour, systematic size, species, and ensonifying frequency are among the prominent factors which determine values and characteristics of the squid target strength. Furthermore, for future measurements, the effect of density and sound speed differences between squid body and surrounding medium, and the uniqueness of swimming behaviour must be considered.

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