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STUDIES ON INDIRECT AND DIRECT METHODS OF *IN SITU* FISH TARGET STRENGTH MEASUREMENT

by

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(Prepared for the December 17, 1975, meeting on "Acoustic Surveying of Fish Populations" at The Fisheries Laboratory, Lowestoft, England.)

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December 6, 1975

INTRODUCTION

The estimation of absolute fish abundance using echo integrators requires knowledge of the echo sounder and integration system parameters and, in many cases estimates of the mean fish target strength. Relationships between fish and target strength have been developed, e.g. Love (1971), Goddard and Welsby (1973), and Nakken and Olsen (1973). However, due to the unknown effects of the fish handling (confinement, anesthetization, killing, etc.,) necessary to make the measurements, and the usually unknown orientation and aspect angle of the surveyed fish population, the application of a particular target strength to length relationship will usually provide biased target strength estimates. A theoretically promising approach is to estimate the target strengths of individual fish *in situ*.

An *in situ* method of target strength estimation was developed by Craig and Forbes (1969) and a variation of this method has been employed by Midttun and Nakken (1971). Using information on the transducer beam apttern, these methods convert echo strength distributions to target strength distributions. In the present study the two methods were simulated on a computer in order to obtain information on their potential accuracy in estimating mean target strength (or mean scattering cross section). This paper discusses the results of these simulation studies and compares them with results from an analysis of empirical data on Pacific hake (*Merluccius productus*). In addition, it describes the operation of a new *in situ* target strength measurement system, a dual beam transducer system (Ehrenberg, 1974), which directly corrects the echo strength to target strength for each detected signle fish target. Preliminary results from a brief application of the system to midwater aggregations of Pacific hake are also presented.

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INDIRECT TARGET STRENGTH ESTIMATION

The original method of Craig and Forbes (1969) statistically corrects an echo strength to a target strength distribution using beam pattern directivity measurements. A variation of this method uses only the maximum echo received from a fish as it is repetitively insonified (Midttun and Nakken, 1971). Both methods explicitly assume the fish are distributed uniformly within the sampled volume. In practice, this will not be true.

Methods of Simulation

Echo strength data used in the simulation analysis were produced by assuming a normal fish length distribution, randomly selecting lengths, converting the length distribution to a target strength distribution on the basis of a target strength to length relationship, and finally, applying a random beam pattern effect.

Two length distributions were generated. The first had a mean of 40 cm and a standard deviation of 5 cm. The second, a bimodal distribution, was the sum of two normal distributions with means of 20 and 40 cm and standard deviations of 5 cm. Each randomly selected length was converted to target strength (T) using an equation developed by Goddard and Welsby (1973):

$$T = 25.8 \log L - 5.8 \log \lambda - 35.1\text{db} \qquad (1)$$

where λ is the wave length and L is fish length, both in metres.

A measured and a theroetical transducer directivity pattern were used in the simulation. The theoretical pattern was used to remove the effect of directivity pattern measurement errors. The measured pattern was from a 38 kHz spherical transducer mounted in a parabolic reflector (Fig. 1). The theoretical pattern was constructed using the directivity function ($b(\theta)$) for a circular transducer:

$$b(\theta) = \left[\frac{2\, J_1 \left[(\pi a/\lambda) \sin \theta\right]}{(\pi a/\lambda) \sin \theta} \right]^2 \qquad (2)$$

where a is the transducer diameter, λ is wave length, θ is the angle from the acoustic axis, and J_1 is the first order Bessel Function. The value of a was chosen as 22.6 cm, the effective diameter of the transducer from which the measured directivity patten was taken.

To calculate the beam pattern parameters, a circular beam and identical transmit and receive directivities were assumed. The probability of occurrence of a detected target between two levels of the transducer directivity is related to the ratio of the area enclosed by the two levels to the total area of the directivity function above a threshold value (Fig. 2). The threshold value will in practice be imposed by the background noise level in the survey area and the dynamic range of the equipment in use.

The directivity pattern function probabilities were used to calculate the necessary analysis parameters for the original Craig and Forbes method and to produce the simulated echo strengths. To simulate the maximum method, it was assumed that the maximum echo from each target resulted from its isonification on the transverse acoustic axis. The beam pattern parameters (probabilities) were calculated from distances ($\Delta\theta_i$) measured along a radius of the transverse axis.

Analysis Procedure

For each length distribution, the original Craig and Forbes and the maximum echo method were simulated, using both the measured directivity function and the theoretical directivity function. In all cases sample sizes for the unimodal and bimodal length distributions were 480 and 960, respectively. Each of the eight simulations was run three times, using independent randomizations of the fish length distribution and beam pattern effect. Each of the resulting 24 sets of data were analyzed using 2, 3, and

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6 db class intervals and two methods for treating the occurrence of negative target frequencies. In one method all negative frequencies were set equal to zero. In the other, the frequency distribution was truncated as soon as a negative frequency occurred, provided 75% of the cumulative frequency distribution (determined from application of the first method) had been produced before the negative value occurred. The latter method was used as a compromise in investigating the effect of negative frequencies. The alternative of halting analysis because of a negative value when only a small portion of the target strength distribution had been calculated, was impractical, particularly with the bimodal distribution, when frequencies in the center of the distribution are expected to be small, and any random, or beam pattern parameter estimation, errors might be expected to cause negative values.

Data recorded with a 105 kHz echosounder from midwater hake concentrations in Port Susan, Puget Sound, were analyzed by the two indirect methods.[1/] The beam pattern parameters were calculated by measuring the 3 db point on the beam pattern, calculating the effective diameter of the transducer, and assuming an ideal beam pattern.

Results and Discussion

Table 1 presents estimates of the mean scattering cross section for each of the 144 sets of simulated data. As indicated above, the estimates were generated using the two types of length distribution, the two estimation methods, the two types of directivity functions, the three class interval categories, three independent randomizations, and the two methods of treating negative frequencies. Typical simulated target strength frequency distributions and the actual target strength distribution, constructed by applying equation 1, are shown in Figure 3.

1/ The data were obtained from R. Thorne, University of Washington, Seattle, Washington, who collected the data in March 1974.

In all but three of the 144 sets of data, the mean scattering cross section estimates were less than the actual values. which were .00244m^2 and .00144m^2 for the unimodal and bimodal distributions respectively. The average (over the three independent runs) of the mean scattering cross sections ranged from 57.0 to 84.3% of the true value using the original method and from 75.3% to 90.7% of the true value using the maximum method. In comparing results for the original and maximum methods, it should be noted that violation of the basic assumption hecessary to the latter method, i.e., that the maximum echo is produced as the fish crosses the transverse acoustic axis, may bias the results. In actual field trials, the assumption will not be fulfilled.

A comparison of mean scattering cross sections using measured and theoretical beam patterms show no substantial differences, indicating that beam pattern measurement errors did not significantly affect the operation of the method. However, these results may not be representative of actual field results since the beam pattern directivity functions used in the analysis were also used to simulate the beam pattern effect to produce the echo strength distributions. In practice, the actual beam pattern directivity, which produces the echo strength distribution, must be estimated.

Since both indirect methods use an iterative process, any errors due either to beam pattern measurements or randomness of the fish distribution are compounded with each calculation. The method this provides good estimates of the frequencies in the beginning (larger) decibel categories, but poorly describes the smaller end of the distribution (fig 3).

Halting analysis (in the manner specified above) when frequencies became negative improved the estimates of mean scattering cross section. However, the degree of improvement was not consistent, The effect of the use of different class interval widths (2, 3 and 6 db) was erratic. Use of the 6 db interval with the maximum method resulted in better mean scattering cross section estimates. However, with the original method, differences in results with changes in class interval widths were variable. Detailed analysis of the effects of negative frequencies and differences in frequency distribution class intervals was not attempted. It is apparent, however, that these factors must be evaluated when either of the two indirect methods are to be applied.

It appears that the indirect methods will usually underestimate the mean scattering cross section, assuming the echo sounder system in use has a sufficient dynamic range to detect the full range of target strengths of the fish under investigation. The effect of a threshold value, whether imposed by the dynamic range of the system or from previous knowledge of the target strength of fish under observation will be to underestimate the calculated target strength distribution for small targets (Weimer and Ehrenberg, 1975).

Table 2 presents results from analysis of single fish targets from Pacific hake in Port Susan, Puget Sound. Mean scattering cross sections obtained using the maximum echo method are larger than those obtained using the original Craig and Forbes method. The results indicate the variability to be expected using the indirect methods to analyze echo strength data and generally agree with the results of the simulation analysis.

DIRECT TARGET STRENGTH ESTIMATION

The dual beam target strength analysis system (Ehrenberg, 1974) converts the echo strength of individual fish echoes to target strength. The system utilizes two transducers with their axes aligned (physically the transducers are constructed together in one unit), transmitting on a narrow beam transducer and receiving on both the narrow and a wide-beam transducer. The following description of the operation of the dual-beam system is largely from Ehrenberg (1974).

Single target echoes are isolated from the signal received on the narrowbeam channel on the basis of pulse width. The intensity of the received echo from the two transducers for detected single fish can be written as:

$$I_n = k_1 \sigma b_n^2 (\theta,\phi) \qquad (3)$$

$$I_w = k_2 \sigma b_n (\theta,\phi) b_w(\theta,\phi) \qquad (4)$$

Where I_n and I_w are the received echo intensities from the narrow and wide beams, respectively, σ is the scattering cross section of the fish target at location (θ,ϕ), $b_n (\theta,\phi)$ and $b_w (\theta,\phi)$ are the narrow and wide beam directivity functions, respectively, and k_1 and k_2 are constants. If the wide beam directivity function is approximately unity over the main lobe of the narrow beam (Fig. 4), $b_w (\theta,\phi)$ is one for detected single echoes and the ratio of the two intensities will be:

$$\frac{I_n}{I_w} = \frac{k_1 \sigma b_n^2(\theta,\phi)}{k_2 \sigma b_n (\theta,\phi)} = \frac{k_1}{k_2} b_n (\theta,\phi) \qquad (5)$$

From this, it follows that the scattering cross section of the fish target at location (θ,ϕ) will be:

$$\sigma = \frac{I_n}{k_1 b_n^2 (\theta,\phi)} = \frac{k_1 I_w^2}{k_2^2 I_n} \qquad (6)$$

Values obtained by using equation 6 can be used to estimate mean scattering cross section and its variance.

A problem with <u>in situ</u> target strength estimation techniques is that, in order to isolate single echoes, the received echo intensity, I, must exceed a threshold level, t_o, i.e.

$$I = K \sigma b^2(\theta,\phi) \; t_o \qquad (7)$$

This threshold will be imposed by the noise conditions and dynamic range of the echo sounder system. As a result of this threshold, only fish with large scattering cross sections will be detected in the low directivity portion of the narrow bea, pattern, i.e., there is discrimination against small targets. With dual beam approach, the angles at which targets are recognized can be controlled by using only those echoes for which

$$b_n(\theta,\phi) > t_1 \quad (8)$$

The threshold, t_1, reduces the bias of the estimate of $E(\sigma)$, but also reduces the number of samples and thus increases the variance of the estimate of $E(\sigma)$. The trade-off between bias and variance must be considered in choosing the t_1 threshold. The effect is discussed further in a report by Ehrenberg and Weimer (1974).

Description of Equipment

The application of a 120 kHz dual beam transducer system has recently begun at the U.S. National Marine Fisheries Service's Northwest Fisheries Center in Seattle. The dual beam system is part of a two frequency towed hydroacoustic assessment system which uses a modified 4-foot Braincon V-fin. The fin houses the dual beam transducer and the 38 kHz spherical transducer with reflector referred to above. The dual beam system is built around a Simrad EK120 echo sounder, with an additional receiver and TVG circuit for the wide beam data. The acoustic parameters of the dual beam system are:

Transducer Characteristics

	Pulse Length (ms)	Source Level (db @1m)	TVG Receiver Gain Setting	Receiving Sensitivity (dbV/ bar)	Directivity Index (db)	Efficiency
Narrow beam	0.1-0.6	119.6	40logR	-84.52	26.0	46%
Wide beam	-	-	40logR	-101.33	12.3	20%

Each receiver is equipped with a calibration oscillator which provides a known signal to the input of the receiver allowing constant monitoring of system gain. The two receiver outputs are connected to an interface amplifier which converts the 120 kHz signals to 5 kHz for tape recording.

Methods

Data in ~~for~~ the form of analog signals stored on magnetic tape were obtained using the dual beam system (transmitted pulse length = 0.4 ms) in October, 1975 from a midwater aggregation of Pacific hake off the coast of Oregon. The hydroacoustic data were collected at night when the hake were dispersed and could be detected as single targets within a depth range of 30-110m. A midwater trawl 1/ haul, made to confirm target identification, caught only hake.

The recorded data from the narrow and wide beams were full wave rectified and displayed simultaneously on a memory digital oscilloscope (Nicolet Instrument Model 1090). Single targets were selected on the basis of pulse width of the returning echo and the echo voltages from the two channels were recorded. The deviation of the time varied gain function for each channel from the ideal $40 \log R + 2\alpha R$ were calculated (Fig.5) and used to correct the echo voltages. The echo voltages for each target, on the basis of system parameters, were converted to echo intensities and the scattering cross section for the targetm using equation 6, was calculated. These values were used to construct histograms and compute the variance of the mean scattering cross section. Various levels of the t_1 threshold were imposed and the effect on the scattering cross section means and histograms was observed.

Preliminary Results

The number of single targets analyzed was only 207, In order to

1/ A Herman Engel type trawl was a 14m vertical mouth opening- mesh size (stretch measure) tapered from 56 cm in the forward section to 3.8 cm in the codend.

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fully evaluate the dual beam system and its potentials, more and larger samples must be processed.

Some results of the dual beam analysis are presented in Figure 6. The distributions were nearly identical for t_1 threshold values of -8.0 db and -6.0 db. This was due to the small reduction in number of observations, i.e., from 207 to 202. The mean scattering cross section estimates decrease consistently as the t_1 threshold is reduced to -4.0, and -3.0, -2.0 and ±1.0 db. Estimates of mean scattering cross section plotted versus t_1 thresholds are presented in Figure 7. The estimates ranged from .00260m^2 for t_1 = -0.5 db to .00425m^2 for t_1 = -8.0 db, corresponding to target strength values of -36.2 to -34.7 db respectively.

Ehrenberg and Weimer (1974) have computed the normalized root mean square error zs a function of the number of fish targets processed, the beam pattern threshold, t_1, and the system dynamic range. These simulated data suggest the beam pattern threshold in the present analysis (N = 207, 20 db dynamic range) should be about -3 db to minimize the error. Imposing this threshold results in a mean scattering cross section estimate of .00314m^2 corresponding to a target strength of -36.0 db Ehrenberg and Weimer (1974) have also shown that the effect of the t_1 threshold is reduced when the system dynamic range is increased.

Figure 9 shows the results of an analysis of the narrow beam data using the original Craig and Forbes method. The mean scattering cross section from this distribution was .00298m^2, which agrees rather closely with the dual beam results- however, the shapes of the target strength histograms are not similar. Whether the close agreement in mean scattering cross section will be consistent can only be determined by further experimentation. Results of simulation in the present paper and simulation analysis by Ehrenberg (1974) indicate that close agreement between the two methods is not to be expected.

The mean target strength predicted by Goddard and Welsby (1973) on the basis of fish lengths (N = 62, mean, 51.4 cm, standard deviation 2.4 cm) in the trawl by equation (1) is -31.5 db. Goddard and Welsby made target strength measurements from fish targets confined in cages at the center of the acoustic cone. The mean scattering cross section of $.00891m^2$ corresponding to a target strength of -31.5 db is 4.5 db over that estimated by the dual beam method. Several factors may contribute to this difference:

(1) The fish observed by the dual beam system are presented at a larger range of aspect angles (away from the center of the beam) decreasing the estimate of average target strength. This would also help to account for the wider spread in target strength distribution resulting from dual beam analysis.

(2) Behavioural effects such as feeding, vertical migrations, etc., will be different between free swimming and confined fish, thus affecting the di cribution of observed aspect angles.

(3) Differences in the transducer temperature during calibration of the dual beam system and those during operation may have caused some error in the results. The transducers were calibrated at a temperature of $19.7^{o}C$, while the temperature at the transducer when the data for the present study were collected was $12.2^{o}C$. The effect of temperature on the transducer parameters is being investigated.

The dual beam results presented in this paper must be considered preliminary. Before the system can be effectively evaluated, more and larger samples must be analyzed. The dual beam signle target recognition and analysis are in the process of being computerized. A large mini-computer (PDP-11/45) is being programmed to sample the hydroacoustic signal, detect single targets on the bases of target pulse width, and

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This computerized dual beam analysis system will be functional by January, 1976, and should facilitate more complete analysis of threshold and sample size effects.

Acknowledgements

The author would like to thank Messrs. J. Ehrenberg and M.Nelson for their useful discussions and review of the manuscript.

Footnote

Mean Target Strength results for Hake from 120 Dual Beam System should be increased by 3.4 dB due to incorrect calibration.

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Table 1. Estimates of mean scattering cross section (σ) generated by the simulation analysis.

Method	Class interval (dB) Beam Pattern	Run	Unimodal Dist. (σ=.00244) All negative frequencies set to zero 2	3	6	Unimodal Dist. Some frequencies not used (see text, p.4) 2	3	6	Bimodal Dist. (σ=.00144) All negative frequencies set to zero 2	3	6	Bimodal Dist. Some frequencies not used (see text, p.4) 2	3	6
Original	Measured	1	.00156	.00141	.00158	.00221	.00211	.00158	.00091	.00091	.00091	.00114	.00091	.00091
		2	.00148	.00152	.00166	.00192	.00169	.00166	.00098	.00095	.00095	.00098	.00095	.00095
		3	.00120	.00124	.00125	.00204	.00139	.00140	.00094	.00106	.00106	.00110	.00106	.00159
		x̄	.00141	.00139	.00150	.00206	.00173	.00155	.00094	.00097	.00097	.00107	.00097	.00115
		% True Value	57.9	57.0	61.3	84.3	70.9	63.4	65.5	67.6	67.6	74.5	67.6	79.9
Original	Theoretical	1	.00153	.00162	.00165	.00174	.00174	.00165	.00112	.00108	.00105	.00115	.00108	.00105
		2	.00141	.00138	.00147	.00150	.00144	.00147	.00087	.00086	.00087	.00108	.00113	.00087
		3	.00158	.00144	.00170	.00222	.00144	.00170	.00098	.00095	.00098	.00105	.00094	.00098
		x̄	.00151	.00148	.00161	.00182	.00154	.00161	.00098	.00096	.00097	.00109	.00105	.00097
		% True Value	61.7	60.7	65.8	74.6	63.1	65.8	68.8	66.9	67.1	75.9	72.9	67.1
Maximum	Measured	1	.00166	.00166	.00194	.00179	.00176	.00200	.00117	.00114	.00129	.00124	.00115	.00129
		2	.00178	.00175	.00207	.00212	.00175	.00207	.00122	.00115	.00132	.00123	.00116	.00132
		3	.00208	.00210	.00244	.00229	.00230	.00244	.00114	.00118	.00131	.00122	.00118	.00131
		x̄	.00184	.00184	.00215	.00207	.00194	.00217	.00118	.00116	.00131	.00123	.00116	.0013[illegible]
		% True Value	75.4	75.3	88.1	84.7	79.4	88.9	81.7	80.3	90.7	85.4	80.8	90.7
Maximum	Theoretical	1	.00207	.00207	.00231	.00233	.00209	.00231	.00114	.00115	.00127	.00114	.00115	.00127
		2	.00183	.00181	.00202	.00185	.00181	.00202	.00123	.00124	.00133	.00126	.00124	.00133
		3	.00170	.00171	.00190	.00174	.00171	.00190	.00114	.00114	.00126	.00115	.00114	.00126
		x̄	.00187	.00186	.00208	.00197	.00187	.00208	.00117	.00118	.00129	.00128	.00118	.00129
		% True Value	76.5	76.4	85.1	80.9	76.6	85.1	81.2	81.7	89.5	89.1	81.7	89.4

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Table 2. Estimate of mean scattering cross section of Pacific hake obtained using indirect methods of target strength estimation. Data were collected in Port Susan, Puget Sound in March, 1974 using a 105kHz echosounder with a pulse length of 0.6 ms. Data were tape recorded at5kHz.

Method	Depth (m)	Frequency distribution class intervals (db)	N	Estimated mean scattering cross-section m^2
Original	71 - 75	2	127	.00039
		3		.00049
		6		.00055
"	75 - 79	2	193	.00041
		3		.00038
		6		.00041
"	79 - 83	2	277	.00061
		3		.00063
		6		.00075
Maximum	71 - 75	2	63	.00088
		3		.00087
		6		.00109
"	75 - 79	2	91	.00079
		3		.00081
		6		.00096
"	79 - 83	2	81	.00092
		3		.00089
		6		.00108

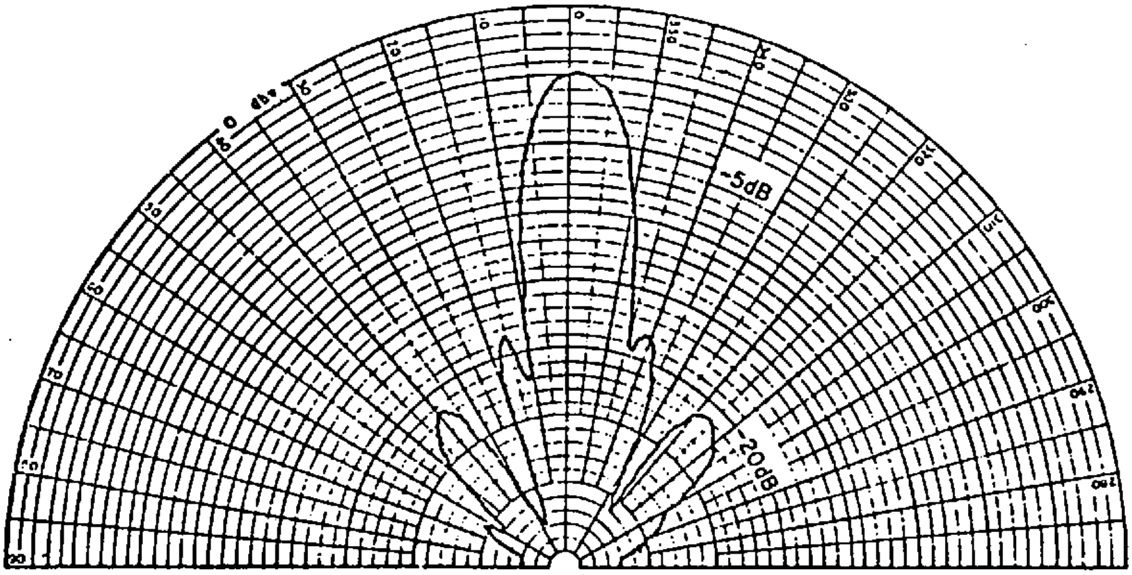

Figure 1. Beam pattern of 38 kHz transducer (Ehrenberg and Acker, 1974).

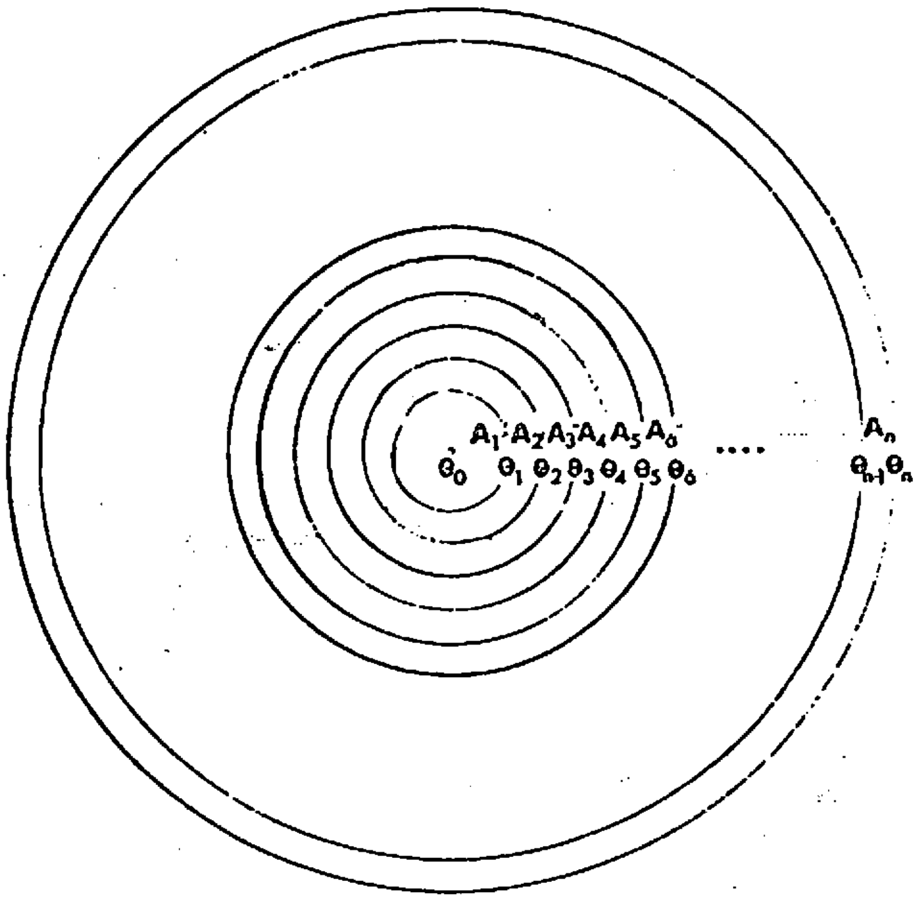

Figure 2. Diagram of the cross section of a circular transducer beam. The circles shown indicate equally spaced (in dB) isopleths of the directivity pattern function. The area between isopleths (A_i) is $\pi(\sin\theta_i)^2 - \pi(\sin\theta_{i-1})^2$, where $\theta_o = 0$. The distance between isopleths is $\theta_i - \theta_{i-1}$.

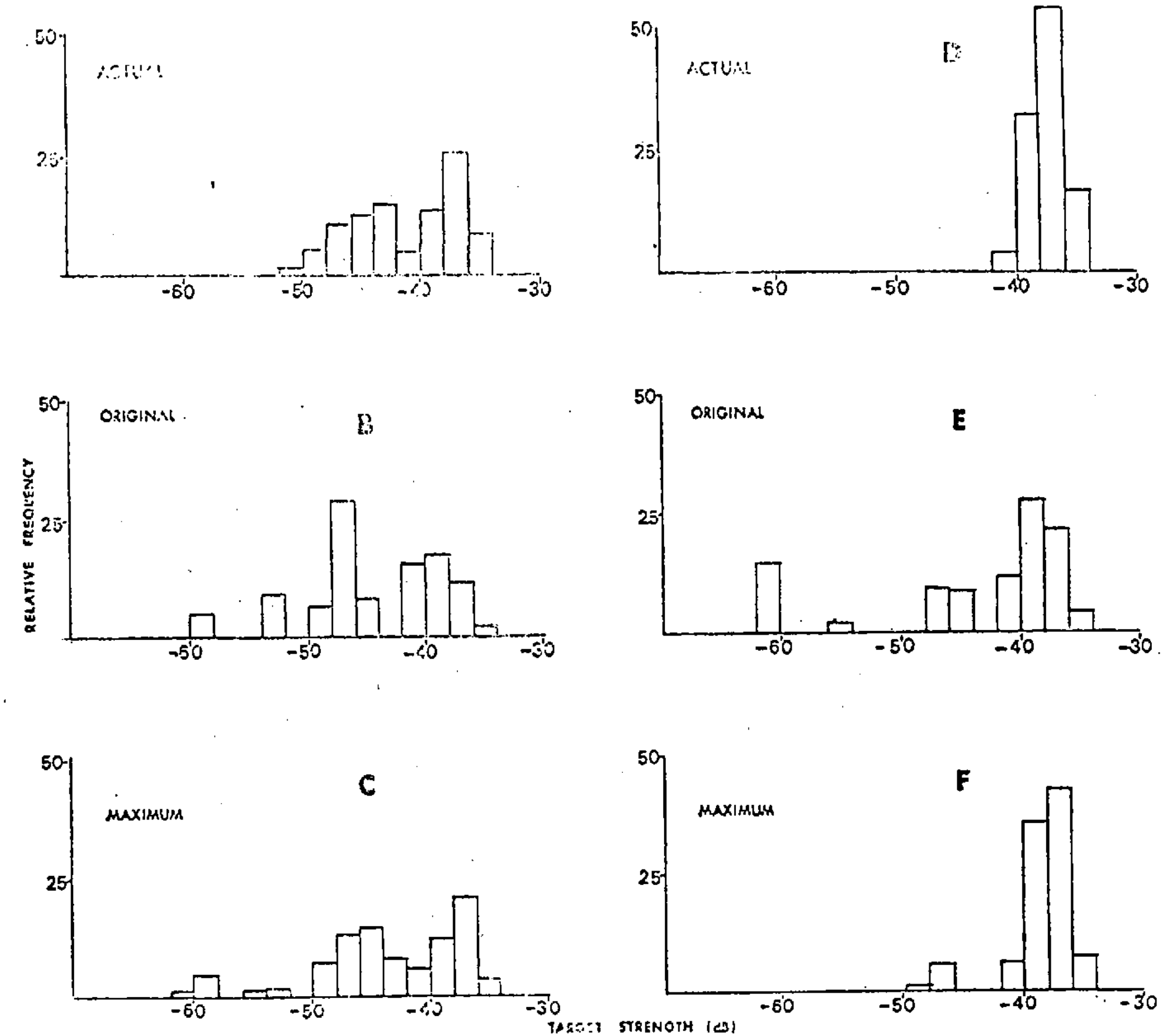

Figure 3. Example of simulation results using the original Craig and Forbes method and the maximum echo method compared with the actual target strength distribution obtained by equation 1. Data are presented from analysis of unimodal (A, B, and C) and bimodal (D, E, and F) length distributions.

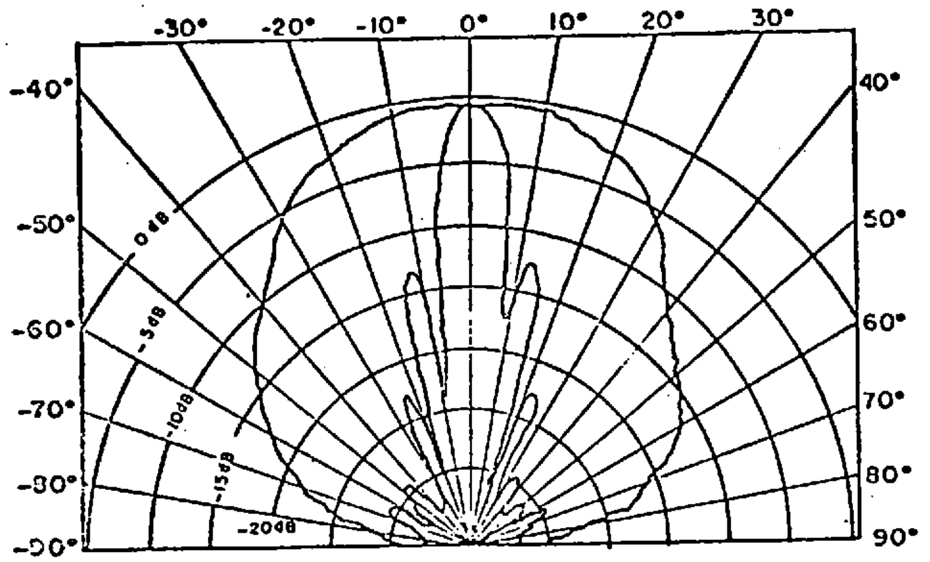

Figure 4. Directivity functions of a 120 kHz dual beam transducer (Ehrenberg and Acker, 1974).

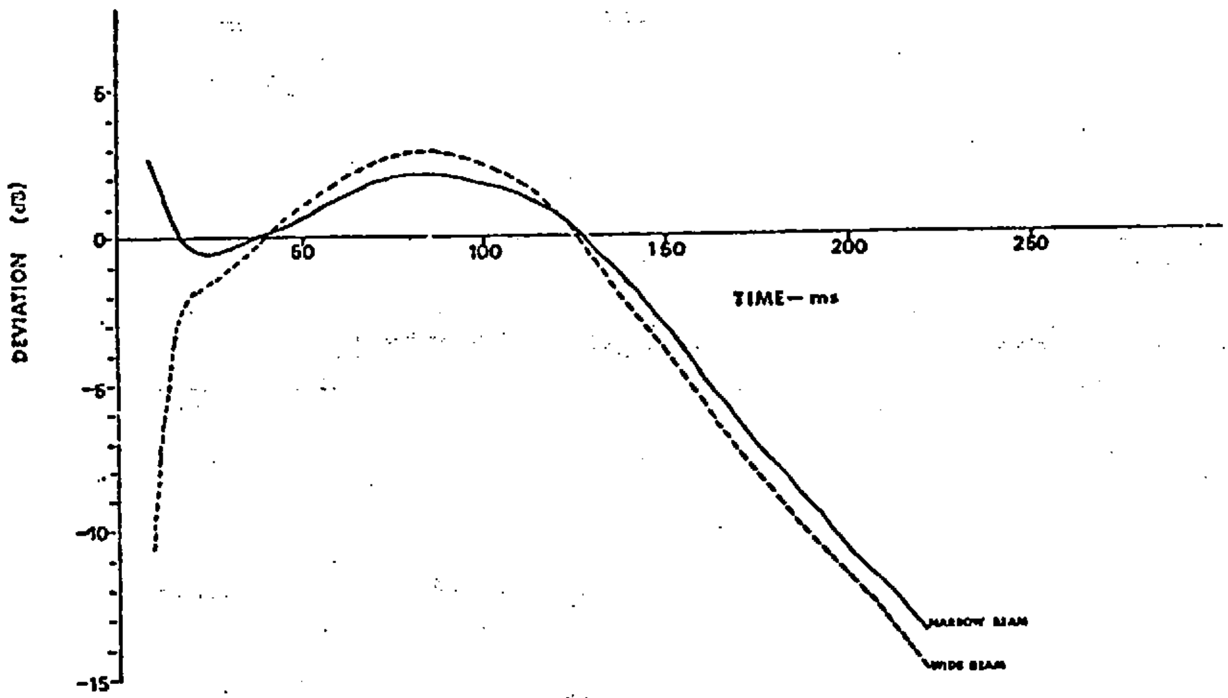

Figure 5. Deviation of the measured TVG function from ideal 40 log R + $2\alpha R$ for the narrow and wide beam receivers.

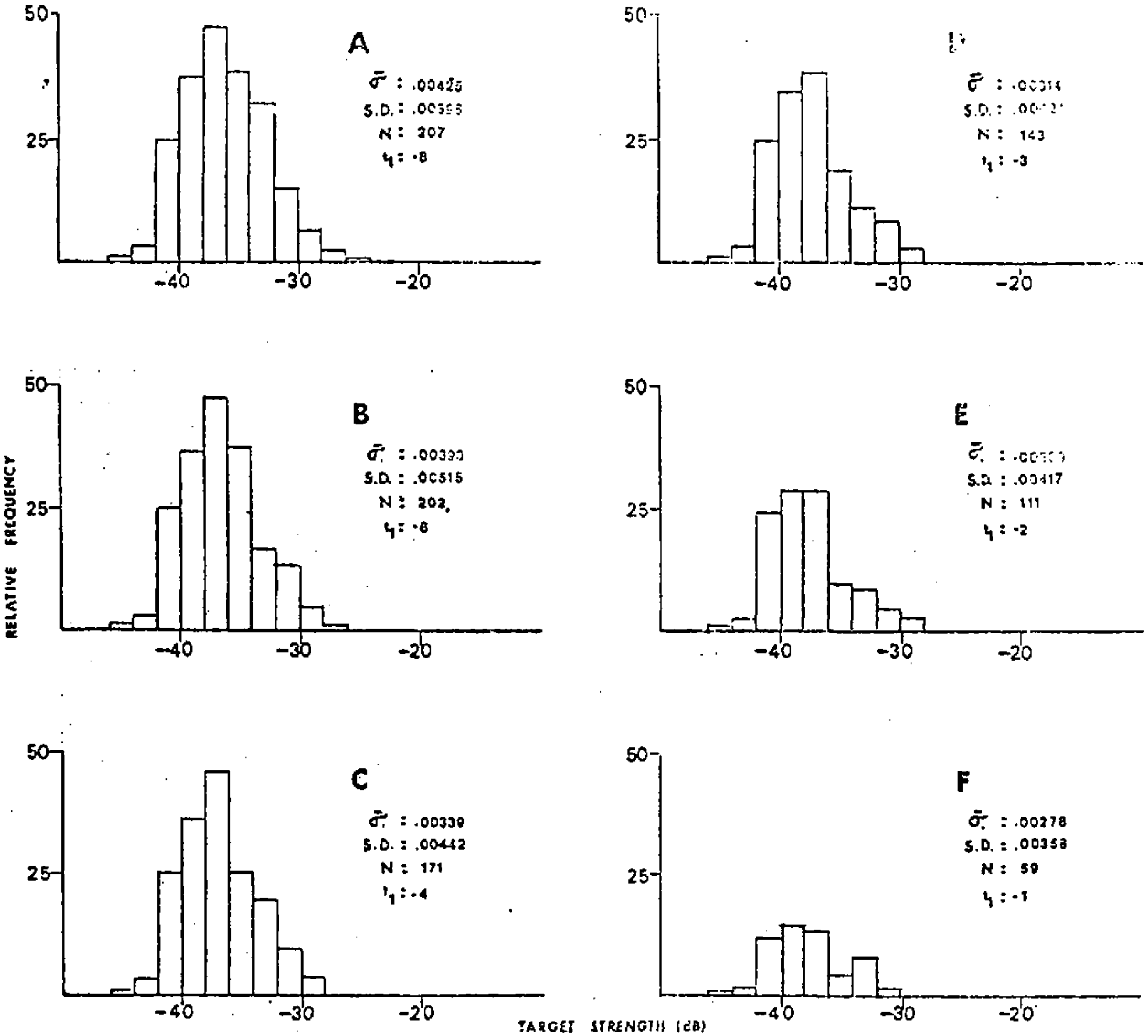

Figure 6. Results of dual beam analysis using various beam pattern threshold values, t_1.

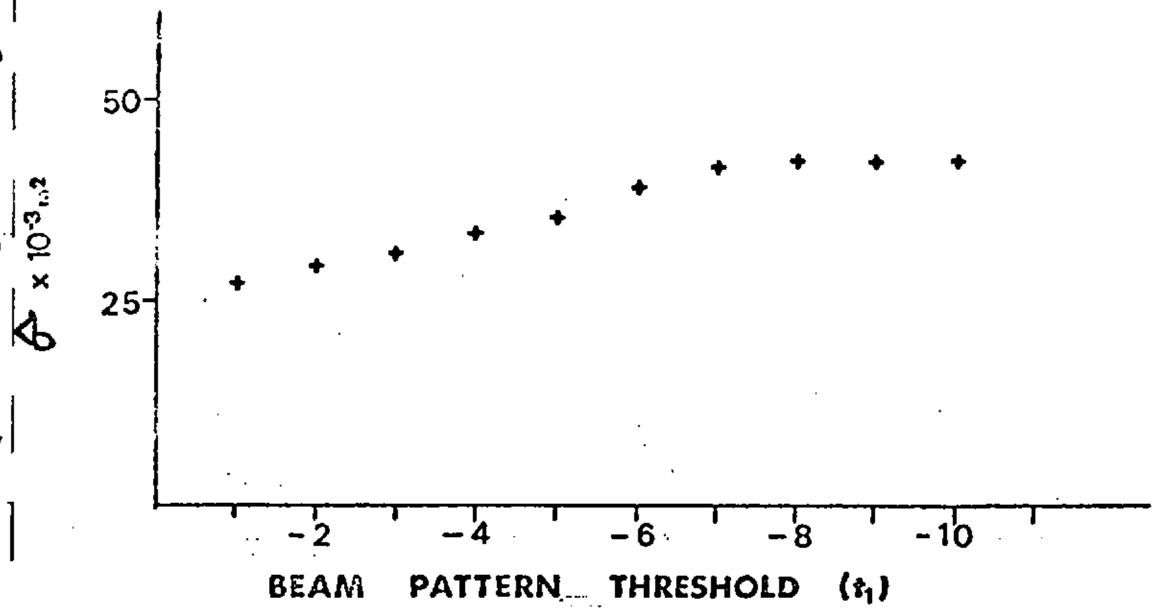

Figure 7. Plot of mean scattering cross section estimates ($\hat{\delta}$) versus the t_1 threshold values.

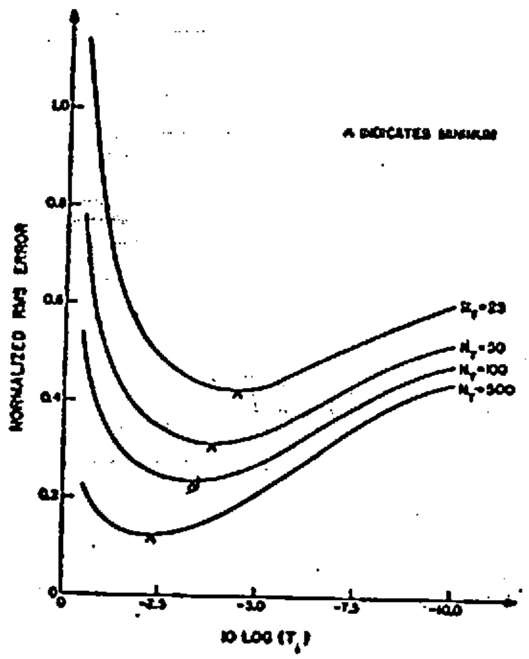

Figure 8. Normalized rms error as a function of the beam pattern threshold, t_1, and the number of echoes N_t greater than t_0, calculations made for a normally distributed target strength distribution with a mean of -30db and standard deviation of 5db. t_0 threshold was set at -40db, assuming 20db dynamic range in the system (Ehrenberg and Weimer, 1974).

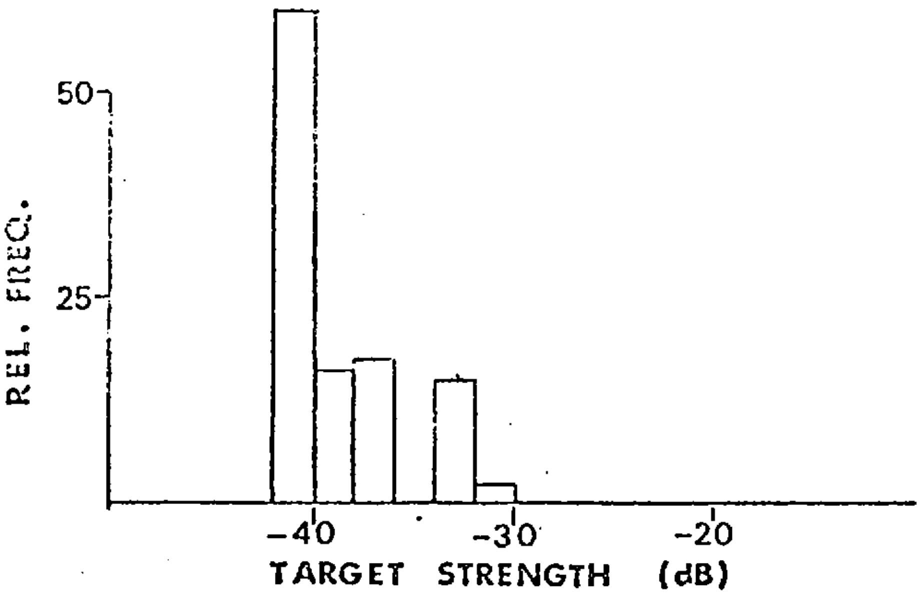

Figure 9. Results of the analysis of the narrow beam data using the original Craig and Forbes method.

DISCUSSION FOLLOWING THE PAPER BY MR.J.J.TRAYNOR : STUDIES ON INDIRECT AND DIRECT METHODS OF IN-SITU FISH TARGET STRENGTH MEASUREMENT.

DR.BERKTAY: How are you introducing the threshold t_1 (equation 8).

MR.TRAYNOR: It is calculated from the series of equations rejecting any value of bn (0 Ø) below a certain level.

DR.BERKTAY: It can be done by simulation but can you do it in practice ?

MR.TRAYNOR: This was an actual experiment on a group of fish.

DR.CUSHING: Did you have a cod end cover on the trawl because it could have been that some of the fish were smaller in the echo sounder sample than in the trawl sample ?

MR.TRAYNOR: Yes, we used a cover, but it is possible that there was some difference in this respect.

MR.NAKKEN: I cannot see the difference between the two target strength distributions in Figure 3, that is, the distribution you get by just using one of the beams and a correction with the Craig and Forbes method to the distribution from a dual beam transducer. Is it possible to get a difference during the simulation because there is a set of equations which give the relation between these distributions and whichever way you go the answer should be the same ?

MR.TRAYNOR: The method assumes a uniform fish distribution within the beam. If you have a pattern which places the fish randomly in the beam then this may affect the method.

MR.FORBES: The dual beam should reduce the variance of the estimate, the value would be the same but with reduced variance.

MR.TRAYNOR: No, the results of the simulation work showed that the Craig and Forbes method usually underestimates the mean scattering cross section if the equipment has sufficient dynamic range to detect a full range of target strengths in the population being surveyed.