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MEASUREMENTS OF TARGET STRENGTH AND SPATIAL ORIENTATION OF EUPHAUSIIDS (KRILL).

by

John Dalen
Institute of Marine Research, P.O. Box 1870, N-5011 Bergen, Norway

and

Åge Kristensen
Electronics Research Laboratory, O.S. Bragstads Plass 6,
N-7034 Trondheim-NTH, Norway.

ABSTRACT

The acoustic backscattering properties expressed as the target strength and the spatial orientation expressed as distribution of tilt angles are observed for several size classes of krill.

The target strength for side aspect is presented as function of frequency for two size classes and as function of aspect angles at three different frequencies when stepwise rotating the specimen. Averaged target strength values from samples at 4° intervals when continuously rotating the specimen 360° are also given at nine different frequencies.

Spatial orientation of free-swimming krill is observed by an underwater photocamera mounted on the acoustic transducer frame. This information is read from the photoes and presented as tilt angle distributions.

Résumé

On a étudié les propriétés de réflexion acoustique, exprimées en pouvoir de la cible, et l'orientation spatiale, exprimée en distribution de l'angle d'inclination, en ce qui concerne plusieurs classes de grandeur des euphausides.

Le pouvoir de la cible est présenté en fonction de la fréquence pour deux classes de grandeur et en fonction de l'angle de vue en troix différentes fréquences en notant à pas les spécimens.

Des valeurs du pouvoir de la cible moyennées à intervalles de 4^{o} à la rotation continuelle de 360^{o} des spécimens sont présentées aussi en neuf différentes fréquences.

L'orientation spatiale des euphausides en nage libre a été observées par l'intermédiaire d'une caméra sous-marine montée sur le cadre du capteur acoustique. Cette information a été lue des photos et on la présente en distributions de l'angle d'inclination.

INTRODUCTION

The estimation of zooplankton abundance and their distributions of species and sizes are important for the understanding of the biological processes and resources of the oceans. One possible and promising approach is to observe these features by means of acoustic methods (SCAR 1978, GREENLAW 1979, HOLLIDAY and PIEPER 1980). Quantitative acoustic estimates require that the acoustical scattering properties of zooplankton are known. If the back-scattering characteristics of the scatterers possess any directivity this requires information of how the zooplankton orientates themselves in time and space (SAMEOTO 1979, EVERSON 1981).

When estimating abundances of zooplankton acoustically two basic approaches have been used. In the first one biological data from net and trawl sampling and acoustic measurements at a single frequency are used to establish a regression equation. This equation relates measured volume backscattering strength to zooplankton biomass.

In the second approach a scattering model - empirical or mathematical (ANDERSON 1950, JOHNSON 1977, GREENLAW 1977 and 1979) - for the investigated zooplankton species has to be known. The target strength of the zooplankton under investigation is often a function of both frequency and size and also contains a distinctive transition region. When this is the case it can be shown possible to estimate the biomass and size distribution using a multifrequency sonar system (GREENLAW 1979).

This paper presents some basic results from investigations on krill (Meganyctiphanes norvegica, Thysanoessa raschii and T. inermis) within a project aimed at procurring a shipborne instrumentation set-up for biomass and size estimation of zooplankton.

Organisms of the actual species are directional scatterers within the required frequency region. The target strength is then naturally presented for several orientation angles of the organisms relative to the acoustic axis of the transducer. Information about spatial orientation of free-swimming krill is presented as a tilt angle distribution. The tilt angle is defined as the angle between the horizontal and a line through the eyes and the longitudinal direction of the carapax of the euphausiids, see Fig. 1.

EXPERIMENTAL METHODS

Most of the observations were performed under free field conditions at sea during two periods the summer of 1980 at a site in Northern Norway.

For the target strength observations the euphausiids were captured by a Tucker trawl at the most shallow depth, 30-50 m, at which they appeared during nighttime, i.e. between 2100 and 0200 hrs. This took place in two fjords, Balsfjorden and Ullsfjorden nearby Tromsø. Target strength observations are obtained of both fresh and preserved zooplankton. The krill to be measured fresh were gently transferred to plastic tubs and thereafter to floating plastic pens where they were kept until the measurements took place. The preserved ones to be measured were nitrogen-frozen immediately upon capture and stored at $-25^{o}C$. The last few hours before being measured they were thawed in a controlled manner in a refrigerator.

Organic decomposition of the specimens after being placed in the water required that the measuring sequence of each krill had to be rapidly performed. This decomposition resulted in a decreasing target strength of up till 10 dB after 1 hour. For the preprocessing and to meet the requirements of fast data acquisition an automatic system for measuring the acoustic backscattering strength at several frequencies was designed. Fig. 2 shows a block diagram of the system.

The transducer array consists of 8 individual transducers mounted in an annular frame having a radius of curvature of 2.2 meters, see Fig. 3. The transducers are used both as transmitters and receivers. The measuring frequencies were displaced 1/3 octave within a region ranging from 31.5 kHz to 1.0 MHz.

The specimen was suspended in the joint volume at 3 m depth by two thin, 0.07 mm diameter, nylon lines through its body, see Fig. 4. After suspending each specimen just below the surface, they were examined thoroughly and gently squeezed to ensure that no bubbles were trapped in the body of the animals.

Information about behaviour or rather spatial orientation of free-swimming krill were gathered during a survey in December 1980. An underwater photocamera system was mounted together with the transducer frame (not the one shown in Fig. 3), see Fig. 5. The camera was triggered from the surface upon favourable conditions with regards to the density of krill in front of the system. Only krill located at focus of the photoes and clearly orientated broadside to the camera were analyzed with respect to their tilt angles.

RESULTS

The backscattering properties of an object are often described by its target strength. The target strength is defined as

$$TS = 10 \log (I_s/I_i) \qquad (1)$$

where

I_s is the backscattered intensity from the scatterer, referred to a distance of 1 m from the acoustic center of the target, and

I_i is the intensity in a plane wave incident on the target.

In our experiment we measured the RMS-value of the stationary part of the backscattered pressure pulse averaged over 25 pulses at each frequency.

The target strength versus frequency in side aspect was measured for two size classes of 10 and 15 specimens. The mean total body length, Fig. 1, was 30 mm and 43 mm, respectively. The results are shown in Figs. 6 a and b. Vertical bars are used to indicate the total range of measured values. The standard deviation at all frequencies was for ~~all~~ each specimen less than 1.5 dB. The dots show the arithmetic mean values for all specimens. The stippled curves in Figs. 6 a and b show the predicted target strength from the fluid sphere model (JOHNSON 1977). The parameters used for the sound spred contrast and the density contrast which both strongly affect the predicted values are mean values of those earlier reported for zooplankton (CLAY and MEDWIN 1977, HOLLIDAY and PIEPER 1980). The volume of the sphere is put equal to that of the krill. The equivalent radius related to the size of the krill is determined by a first order regression equation (JOHNSON 1977).

The target strength as function of aspect angle normalized with respect to the maximum value at side aspect is presented at three frequencies, Fig. 7. The cut off part of the 315 kHz-curve below -20° was related to a temporary malfunction of our turntable.

Averaged values of the target strength from readings at every 4th degree when slowly rotating the specimen 3 times 360° are given in Table 1. Differences between these values and their respective maximum values at side aspect are also indicated.

Fig. 8 shows a frequency distribution of the tilt angle from two photoes of free-swimming krill, Thysanoessa inermis and T. raschii, at 40 m depth in Ullsfjorden. The composition of the two species by numbers determined from four Tucker trawl catches in the area showed up to be respectively three to four. The mean total body length was 18 mm for both species all together.

DISCUSSION

The two size classes which produce the results of Figs. 6 a and b also represent two different species of krill. The smallest species was Thysanoessa raschii and the larger one Meganyctiphanes norvegica. The species are physiologically and geometrically very similar. The biochemical composition may, however, be different, e.g. changes in lipid-contents (FALK-PETTERSEN 1981).

The target strength observed for the two classes shows approximately the same frequency dependency. It is a trend of decreasing values with increasing frequency in the region below 200-300 kHz. At higher frequencies the target strength tends to vary around a constant value. The general features of the target strength versus frequency are quite similar to those earlier reported for euphausiids (GREENLAW 1977).

The difference in target strength for the two classes is approximately 10 dB at all frequencies. Under the assumption of the same scattering properties the target strength differences at geometric scattering would be given by the geometrical cross section differences only. This assumption yields a difference of about 3 dB.

To predict the target strength of an organism a scattering model is required. An often used model for zooplankton is that of a fluid sphere (ANDERSON 1950, JOHNSON 1977). Euphausiids are alongated in shape which gives rise to orientation dependent target strength, see Fig. 7. The fluid sphere model cannot predict directional backscattering as observed, but comparison between this model and the measured target strength in side aspect may, however be instructive.

The target strength predicted by this model is a function of the size of the scatterer, the sound speed contrast and the density contrast. JOHNSON (1977) demonstrated that 1% variation in one of the contrasts yielded about 2 dB change in the target strength. The considerable difference observed between the two size classes may be caused by minor variations in the specific contrasts for the two species.

In acoustic determination of size distribution the transition region from Rayleigh to geometric scattering should be located. Our results do not indicate any transition region for the large size class, while for the small one this region seems to be located at approximately 40 kHz (KRISTENSEN and DALEN 1981). The model predicts the transition region at 41 kHz and 58 kHz of the large and small specimen, respectively. The observation of the transition region compared to the prediction from the model yields a downward shift in frequency of about 30% for the small size class. This may have several reasons. An obvious one is the great discrepancy between the geometry of the model and that of the investigated zooplankton. Based on the same relative shift in frequency the expected transition region for the larger size class would be approximately 25 kHz. This is below the frequency region of our experiment, so further considerations about the validity of this expected value cannot be drawn.

In order to establish measurements of abundance of euphausiids, as for fish, by acoustic methods the target strength-to-size functions should be based on averaged values (SAMEOTO 1980, EVERSON 1981, FOOTE 1978 a, b). A way to do this is to average the individual empirical target strength functions with respect to a certain behaviour of the species, i.e. the actual orientation distributions.

Examples of what basic information required for such an analysis are presented in Figs. 7 and 8, target strength versus aspect angle and frequency distribution of tilt angles, respectively.

The target strength versus tilt angle shows a relatively well defined main lobe at side aspect for all three frequencies. As expected the lobe width increases with decreasing frequency. At other aspects the target strength is rather varying. Dependent on the ratio between the size of the organism and the acoustic wavelength constructive and destructive interference will occur at different aspects. Hence this variation is probably caused by interference of scattering from different parts of the scatterer.

The results shown in Table 1 indicate the differences between an averaged target strength and that of the side aspect. The frequency region, 63-500 kHz, from which we have datas is determined of those frequencies where we have a sufficient signal to noise ratio for all aspect angles.

The ΔTS is somewhat low - approximately 4-5 dB - because of the before mentioned organic decomposition since this particular measurement took place about 30-45 min after the krill being submerged. Note that the ΔTS is rather stable over the entire frequency region.

The frequency distribution of the tilt angle, Fig. 8, yields a mean value of the tilt angle of -9.8° with a standard deviation of 34.1°. This says that the major part of the krill is migrating downwards at this depth, 40 m, and moment, 0200 hrs. Simultaneous observations from an 120 kHz echosounder together with an echo integrator showed a downward migration of the plankton-layer at that depth and hour.

Another interesting observation from the photoes and also from the floating pens is that the krill is almost always moving around with its body rather stretched whether it swims horizontally, vertically or at any other tilt angle.

Here we would like to stress the need for further observations of acoustic scattering properties and behaviour of zooplankton from all investigators concerned. Our project will in nearest future focus on measuring backscattered echo intensity from different species together with photographic studies of the behaviour - all under free-field conditions.

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REFERENCES

ANDERSON, V.C. 1950. Sound scattering from a fluid sphere. J. Acoust. Soc. Am., 22: 426-431.

CLAY, C.S. and MEDWIN, H. 1977. Acoustical Oceanography. Principles and Applications. pp. 218. John Wiley & Sons, New York.

EVERSON, I. 1981. Diurnal variations in mean volume backscattering strength of an Antarctic krill (Euphausia superba) patch. J. Plankton Res., (In press).

FALK-PETTERSON, S. 1981. Ecological investigations on the zooplankton community of Balsfjorden, Northern Norway: Seasonal changes in body weight and the main biochemical composition of Thysanoessa inermis (Krøyer), T. raschii (M. Sars), and Meganyctiphanes norvegica (M. Sars) in relation to environmental factors. J. exp. mar. Biol. Ecol., 49: 103-120.

FOOTE, K. 1978 a. Effect of fish behaviour on echo energy: the need for measurements of orientation distributions. J. Cons. int. Explor. Mer., 39: (2) (In press).

FOOTE, K. 1978 b. Averaging of fish target strength functions. J. Acoust. Soc. Am., 67(2): 504-515.

GREENLAW, C.F. 1977. Backscattering spectra of preserved zooplankton. J. Acoust. Soc. Am., 62: 44-52.

GREENLAW, C.F. 1979. Acoustical estimation of zooplankton populations. Limnol. Oceanogr., 24: 226-242.

HOLLIDAY, D.V. and PIEPER, R.E. 1980. Volume scattering strength and zooplankton distributions at acoustic frequencies between 0.5 and 3 MHz. J. Acoust. Soc. Am., 67: 135-146.

JOHNSON, R.K. 1977. Sound scattering from a fluid sphere revisited. J. Acoust. Soc. Am., 61: 375-377.

KRISTENSEN, Å. and DALEN, J. 1981. Measurements of acoustical backscattering strength from euphausiids (krill). In Ultrasonics International 81 Conference Proceedings, Brighton, Great Brittain, 30 June-3 July 1981 (In press).

SAMEOTO, D.D. 1980. Quantitative Measurements of Euphausiids Using a 120-kHz Sounder and Their in situ Orientation. Can. J. Fish. Aquat. Sci., 37: 693-702.

SCAR. 1978. Meeting of SCAR group of specialists on the living resources of the Southern Oceans. Final Report. pp. 31 and Ann. 1-7.

Table 1. Target strength in side aspect, averaged target strength and their difference, ΔTS, versus frequency.

Frequency [kHz]	63	80	100	160	200	250	315	400	500	Average
Target strength, side aspect	-75.5	-77.0	-79.0	-77.5	-82.0	-78.5	-75.0	-77.0	-74.0	-76.7
Rotated average value	-87.0	-89.5	-92.5	-88.0	-93.0	-87.5	-87.5	-90.0	-89.5	-89.0
ΔTS	-11.5	-12.5	-13.5	-10.5	-11.0	- 9.0	-12.5	-13.0	-15.5	-12.3

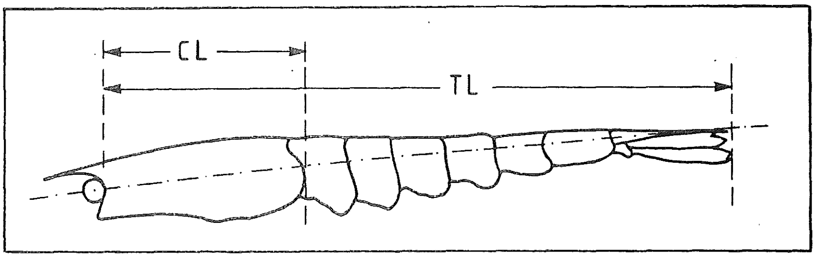

Fig. 1. Sketch of a krill in side aspect. The dashed line and the horizontal defines the tilt angle.

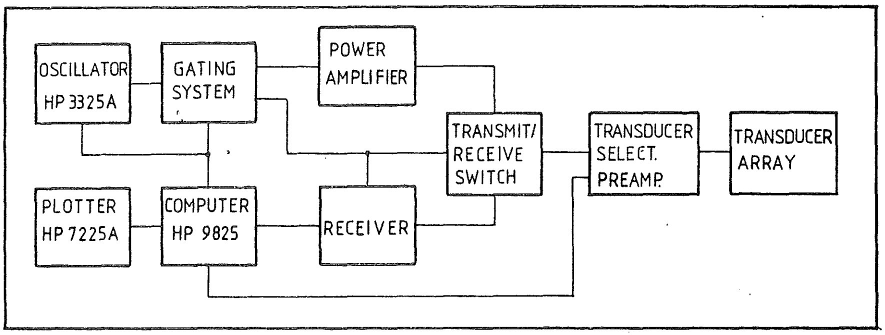

Fig. 2. Block diagram for the measuring equipment.

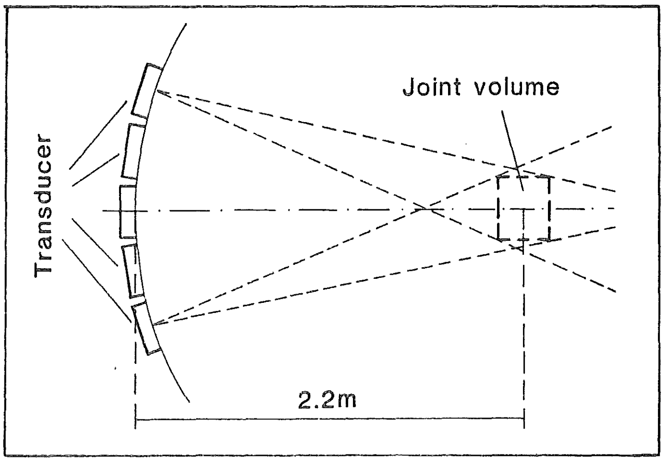

Fig. 3. Sketch of the transducer arrangement.

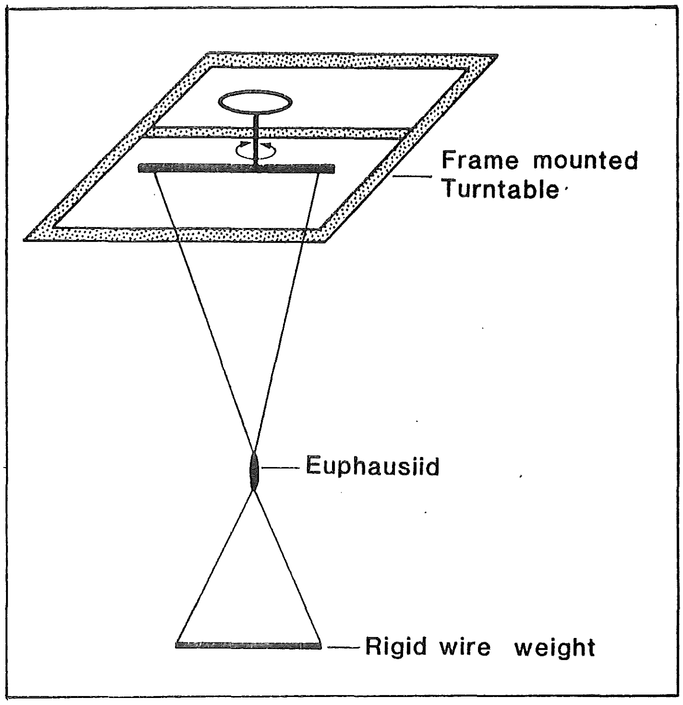

Fig. 4. Sketch of the suspension system for the krill.

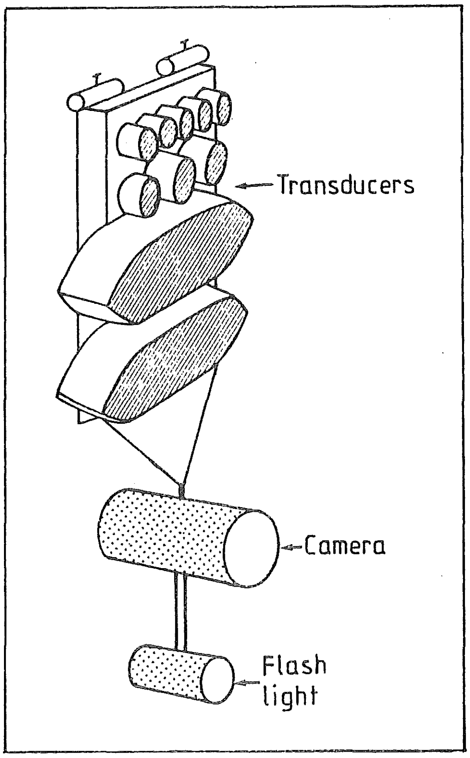

Fig. 5. Sketch of the transducer frame and the camera system.

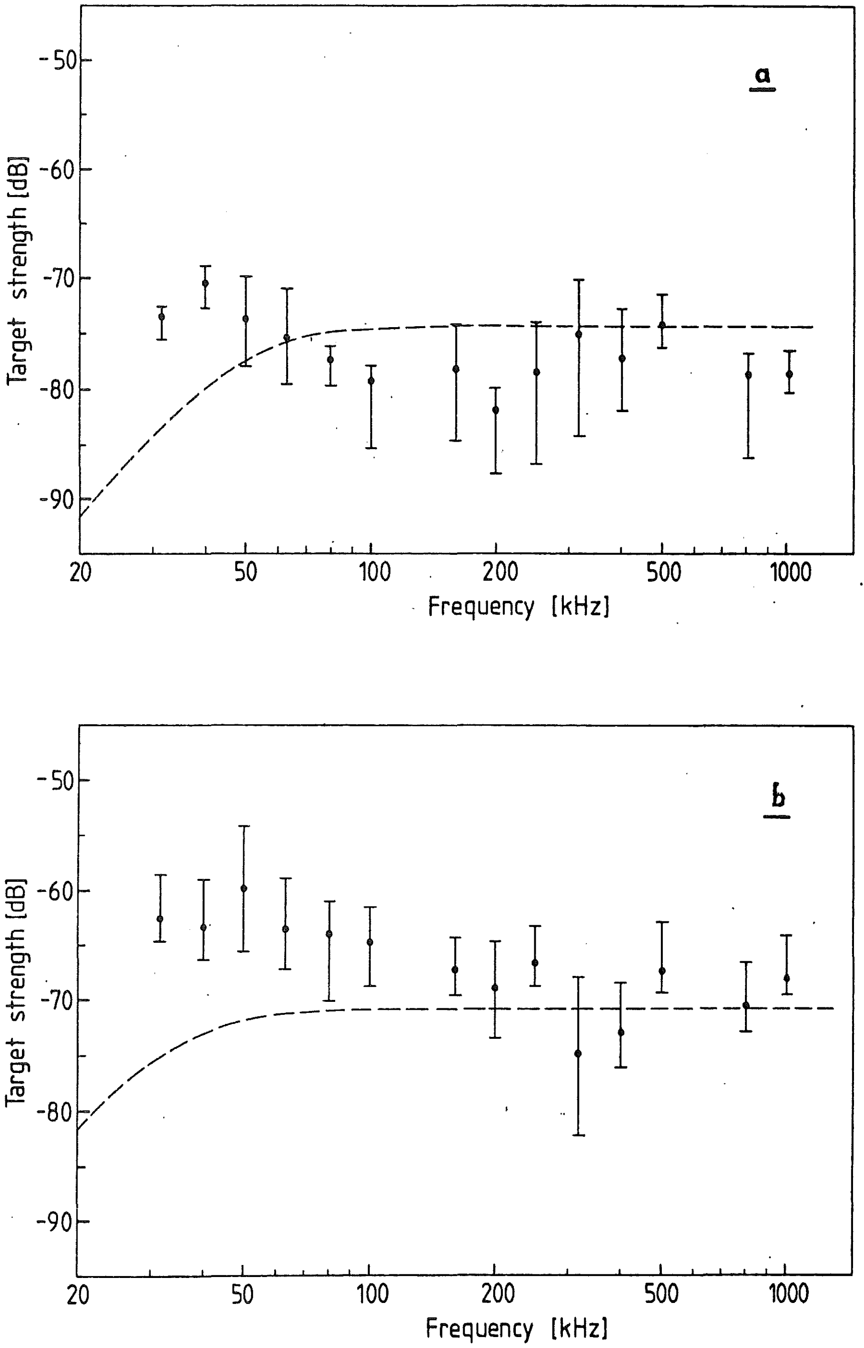

Fig. 6. Target strengths of krill versus frequency.
(b) - size class of 43 mm mean total body length,
(a) - size class of 30 mm mean total body length.
Dashed line: predictions from the fluid sphere model.

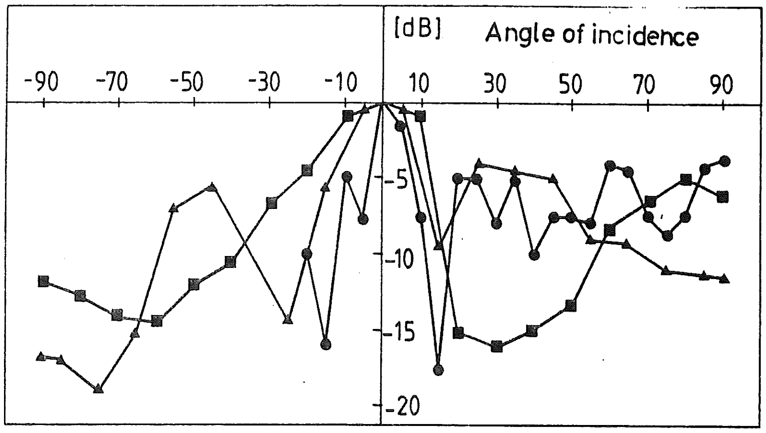

Fig. 7. Normalized target strength of krill versus angle of incidence at:
■ - 40 kHz, ▲ - 80 kHz, and ● - 315 kHz.

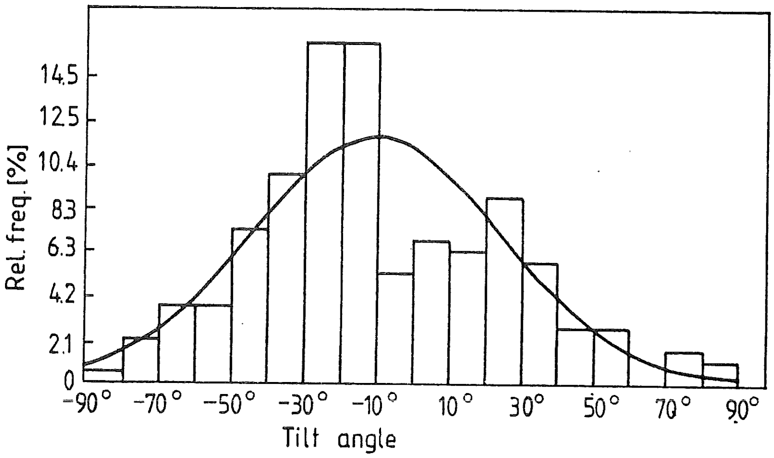

Fig. 8. Relative frequency distribution of tilt angles of krill observed by photocamera at 40 m depth and at 0200 hrs, Dec. 1980. Total numbers of specimens analyzed are 192. The indicated Gaussian curve has equal mean value and standard deviation as the observed distribution.