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Acoustic target strength of krill

ABSTRACT: The compilation of experimental data on krill target strength is performed and results compared with the theory. A modification of the Johnson's theory is proposed to fit experiment.

Key words: Antarctic, acoustic, krill

1. Introduction

Conventional sampling of zooplankton abundancies by counting subsamples of specimens caught with nets are very tedious and time consuming. They have many drawbacks such as avoidance and clogging in nets as well as problems associated with the nature of sequential sampling. At the moment acoustic surveys are the best methods to obtain information on krill abundance in a particular region of Antarctic. Although acoustical sampling yields no specimens of organisms it offers coverage of large areas within a short time and gives good resolution. The acoustic estimates are based on a following relation between amount of krill and its acoustical backscattering strength:

$$TSV = TS + 10 \log \varrho \tag{1}$$

where TSV — volume backscattering strength measured by echosounder in dB,
TS — Target strenth of a single krill specimen in dB,
ϱ — density of krill in krill/m^3.

It is clear from the formula that the accuracy of the acoustical estimates depends on the accuracy of measurements of TSV and the knowledge of the target strength of a single specimen. The work reported here was undertaken to compile the results for the target strength of krill and to compare them with the theory.

The target strength of an object is defined as:

$$TS = 10 \log \frac{J_r}{J_0} = 10 \log \frac{\sigma}{4\pi} \tag{2}$$

where J_0 — incident sound intensity at the object,
J_r — scattered sound intensity at 1m from the center of the object,
σ — acoustical backscattering cross-section of the object.

2. Experimental data

It is well known that amount of acoustic energy scattered by the object depends on frequency of the sound, dimensions of the object, direction from which the object is insonified and on physical parameters of the object such as density and sound velocity. All available experimental data give relation between the target strength and the length of the animal since the last parameter is the most important and the easiest to measure.

Kalinowski, Dyka and Kilian (1981) have received for the target strength of krill the following regression curve:

$$TS = 2.3L - 72$$

where L is the length of krill in cm. The measurements were performed on preserved specimens at frequency 159 kHz in a tank with fresh water.

During BIOMASS-FIBEX measurements of krill target strength were performed on fresh animals by groups of Japan, USSR and Chile. Results received (reported at the meeting in Hamburg in September 1981, not published yet) are following:

Japan $TS = -75.1 + 23.05 \log L$ measured at 200 kHz,
USSR $TS = -77.2 + 20 \log L$ measured at 120 kHz,
Chile $TS = -65.1$ dB for $L = 46$ mm measured at 120 kHz.

All these results as well as the theoretical curves are shown in Figure 1. It can be seen that the differences between results received by different authors are in average as large as 5 dB. The probable cause for it is that they were taken at different frequencies on different populations and using different methods. It is clear that the best solution is to find a scattering model which will predict scattering strengths over wide ranges of frequencies and organism size and will account for other parameters that the target strength depends on.

3. Theoretical model

Greenlow (1977) found that the scattering behavior of a preserved single specimen of *Euphausia* was well approximated by a fluid sphere scattering model (Johnson 1977). In this model a zooplankter is considered as a sphere of a volume equivalent to that of krill volume and ϱC equal to ϱC of krill. Calculating the acoustic field scattered by such a sphere Johnson got the following approximate formula for the acoustical backscattering cross-section:

$$\sigma = 4\pi a^2 \left(\frac{1-gh^2}{3gh^2}+\frac{1-g}{1+2g}\right)^2 \left(\frac{2\,(ka)^4}{2+3\,(ka)^4}\right) \tag{3}$$

where $g = \frac{\varrho_k}{\varrho}$ is the ratio of the density of krill to the density of the sea water surrounding it

$h = \frac{C_k}{C}$ is the ratio of the sound velocity of krill to the sound velocity of the surrounding sea water

$k = \frac{2\pi f}{C}$ is the wave number in the medium

a is the radius of an equivalent sphere

For calculations the following values of parameters were taken: $\varrho_k = 1.09 \times 10^3$ kG/m^{-3} (from Wolnomiejski, Witek and Czykieta 1980), $\varrho^3 = {}^3 1.025 \times 10^3$ kG/m^{-3}, C_k (at 2°C) = 1473.96 m/s^{-1} (there is no avalable data on sound velocity of krill so the value for *Euphausia pacifica* was taken according to Greenlow (1977)), C (at 2°C) = 1458 m/s^{-1}, f = 120 kHz. The relation between a and L was calculated from the experimental regression relation between weight (W) and length (L) (Wolnomiejski, Witek and Czykieta 1980):

$$W = AL^B$$

where $A = 0.0018$, $B = 3.3831$, W is in mg and L is in mm. We assume

$$W = \frac{4}{3}\pi a^3 \varrho = AL^B$$

hence

$$a = \sqrt[3]{3.94 \times 10^{-4}\, L^{3.3831}}$$

which differs a little from the relationship for *Euphausia* cited by Greenlow (1977):

$$a = 0.095 + 0.134L$$

The theoretical curves for preserved and fresh animals differ due to differencies in density and velocity of sound. In our case the difference is less than 0.5 dB so the results presented in Fig. 1 are only for fresh specimens.

4. Discussion

It is evident that all experimental data although sparse have values much greater than the theoretical curve. To fit better experimental data it was assumed that the radius of the equivalent sphere is equal to half of the

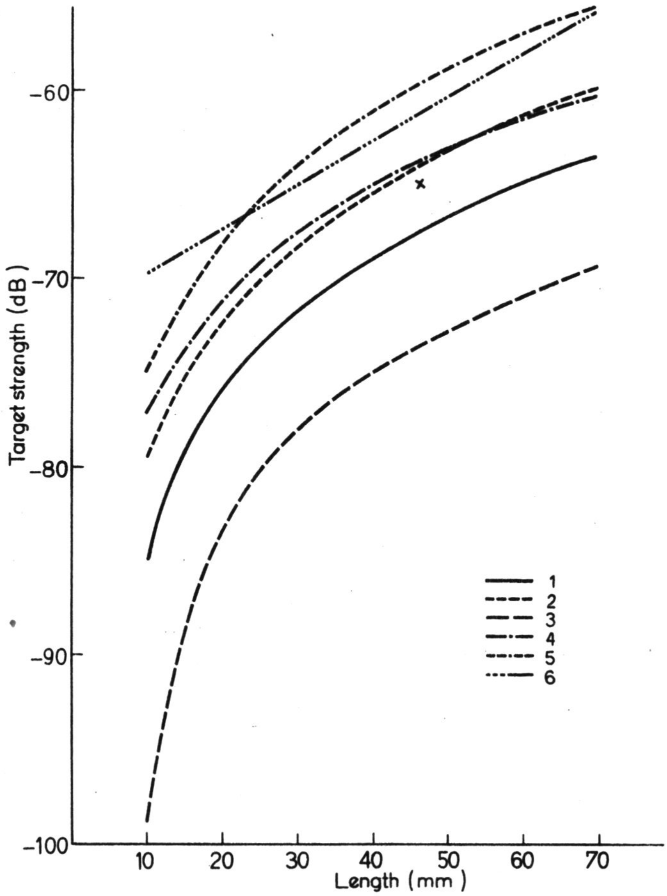

Fig. 1. The target strength of krill

1 — corrected theory, 2 — corrected theory, 3 — Johnson's theory (1977), 4 — Russian data (not published), 5 — Japanese data (not published), 6 — Polish data (Kalinowski, Dyka and Kilian 1980), x — Chilean data (not published).

major axis of the ellipse of a volume equal to that of krill (which is better approximation). It was found for krill that the ratio of the major to the minor axis of the equivalent ellipse is equal 7.8 (Wolnomiejski, Witek and Czykieta 1980). It gives the following relation between a and L:

$$a = \sqrt[3]{3.075 \times 10^{-3}\, L^{3.3831}}$$

If we substitute a into equation (3) we get theoretical line much higher than the Johnson's curve but still lower than the experimental data. The weak point of the theoretical calculations was the assumption that the velocity contrast for krill is the same as that of Euphasiids, which does not have to be true. If we take h=1.05 instead of 1.01 (the values measured by Greenlow (1977) were between 1.00 and 1.04) we fit nearly exactly the Russian data. Sofoulis at al. (1979) for 16 cm long penaeid prawns measured the target strength to be −51.4 dB. If we calculate the target strength of 16 cm long animal according to such corrected theory we get value −51.98 dB. Agreement is surprisingly good. It is obvious that for the consistent comparison between experimental results and the theory we should accurately know all the parameters of equation (3). Only than we can reject theory which differs noticeably from the experiment. It is possible that theory good for Euphausiids is not equally good for krill. We were trying to fit Russian data as it is probable that the experimental results of Japan and Poland (Kalinowski, Dyka and Kilian 1981) are a bit too high since they were taken at higher frequencies 200 and 159 kHz accordingly.

It should be noted that the accuracy of determination of the target strength of krill plays a fundamental role in the evaluation of krill abundance. To illustrate this let us compare the density of krill calculated from equation (1) with the values of TS from Fig. 1 for animals 46 mm long (we assume $TSV = -35$ dB)

Johnson's theory	7244 krill/m^3
Corrected theory 1	1820 krill/m^3
Chilean data	1023 krill/m^3
Corrected theory 2	830 krill/m^3
Russian data	794 krill/m^3
Polish data	473 krill/m^3
Japanese data	309 krill/m^3

I think this example is convincing enough to show how important is the target strength of a single krill for the proper estimation of krill abundance.

5. Резюме

Проведён обзор экспериментальных данных, касающихся силы цели криля (рис. 1). Результаты полученные различными исследователями отличаются в среднем на 5 dB. Полагается, что это различие может быть вызвано различными условиями проведения эксперимента. Экспериментальные данные сравниваются с моделью Джонсона, которая рассмотривает криля как жидкую сферу, объём которой равен объёму криля и акустическая импеданция ϱC равна акустической имеданции криля. Полученная при таком предположении теоретическая кривая отличается довольно сильно от результатов эксперимента. Для сближения теории с экспериментом принято предположение, что радиус сферы должен быть взят равным главной полуоси эллипса, объём которого равен объёму криля. Проведенные расчёты подтвердили правильность такого предположения.

6. Streszczenie

Przeprowadzono kompilację danych eksperymentalnych dotyczących siły celu kryla (Rys. 1). Wielkości uzyskane przez różnych autorów różnią się między sobą średnio o 5 dB. Przypuszcza się, że różnice te mogą być spowodowane różnymi warunkami przeprowadzenia eksperymentu. Wyniki eksperymentalne porównano z teorią Johnsona, która zakłada, że kryl może być potraktowany jak kulka o objętości równej objętości kryla i ϱC równym ϱC kryla.

Różnice pomiędzy otrzymaną krzywą teoretyczną i krzywymi pomiarowymi są niestety dość znaczne. W celu uzyskania lepszej zgodności zaproponowano modyfikację teorii Johnsona polegającą na przyjęciu promienia kulki równym głównej półosi elipsy o objętości równej objętości kryla. Obliczenia wykazały, że w ten sposób uzyskano znaczne zbliżenie krzywej teoretycznej do danych eksperymentalnych.

7. References

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