DETECTION AND QUANTITATIVE ESTIMATION OF KRILL CONCENTRATIONS BY HYDROACOUSTIC INSTRUMENTS

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Abstract

The limited capabilities of existing hydroacoustic instruments in detecting dispersed and surface concentrations of krill lead to considerable underestimates of krill biomass in areas surveyed. The task of detecting surface concentrations of krill can be solved with the help of towed acoustic antennae. The practical possibility of detecting dispersed krill by hydroacoustic instruments was established on board the research vessel Odissey during the international expedition under the FIBEX program. It was shown that the hydroacoustic device Simrad SK-120, with TVG switched off, is capable of registering individual krill at a depth of 50 - 60 m while the vessel is in motion. According to theoretical calculations, the range of detection of individual specimens can be considerably increased at the expense of a rise in the acoustic power of emission.

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DETECTION ET EVALUATION QUANTITATIVE DES CONCENTRATIONS DE KRILL A L'AIDE D'APPAREILS HYDROACOUSTIQUES

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Résumé

Les performances des appareils hydroacoustiques utilisés actuellement pour la prospection des concentrations dispersées ou localisées près de la surface étant limitées, on aboutit à la sous-estimation importante de la biomasse du krill dans les régions étudiées. La détection des concentrations du krill près de la surface devient possible grâce à l'application des transducteurs remorqués. L'expédition internationale réalisée dans le cadre du programme FIBEX a démontré la possibilité réelle de la détection du krill dispersé à l'aide des appareils hydroacoustiques sur le navire de recherche Odyssée. On a établi que le sonar SK-120 Simrads peut enregistrer les spécimens isolés, le bateau étant en marche et le TVG hors service, jusqu'à la profondeur de

50 à 60 m. Selon les calculs théoriques, la portée de détection du krill isolé pourrait être considérablement augmentée grâce à l'élévation de la puissance acoustique.

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DETECCION Y ESTIMACION CUANTITATIVA DE LAS CONCENTRACIONES DE KRILL POR MEDIO DE INSTRUMENTOS HIDROACUSTICOS

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Resumen

Las capacidades limitadas de los instrumentos hidroacústicos existentes en la detección de concentraciones de krill dispersas y de superficie conducen a subestimaciones considerables de la biomasa del krill en las áreas prospeccionadas. La labor de detectar las concentraciones superficiales de krill puede ser resuelta con la ayuda de antenas acústicas remolcadas. La posibilidad práctica de detectar el krill disperso por medio de instrumentos hidroacústicos fue establecida a bordo de la embarcación de investigación Odissey durante la expedición internacional que se realizara bajo del programa FIBEX. Se demostró que el aparato hidroacústico Simrad SK-120, con el TGV desconectado, tiene la capacidad de registrar krill individual a una profundidad de 50-60 m mientras que la embarcación se encuentra en movimiento. Según cálculos teóricos, el radio de detección de especímenes individuales puede ser aumentado considerablemente a expensas de un aumento en el poder acústico de emisión.

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ОБНАРУЖЕНИЕ И КОЛИЧЕСТВЕННАЯ ОЦЕНКА КОНЦЕНТРАЦИЙ КРИЛЯ ГИДРОАКУСТИЧЕСКОЙ АППАРАТУРОЙ

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Резюме

Ограничение возможностей существующей гидроакустической аппаратуры при обнаружении рассеянных и поверхностных концентраций криля приводят к значительной недооценке биомассы криля в обследуемых районах. Задача обнаружения поверхностных концентраций криля

может быть решена с помощью буксируемых акустических антенн. Практическая возможность обнаружения рассеянных концентраций криля гидроакустической аппаратурой была установлена на борту научно-исследовательского судна "Одиссей" во время международной экспедиции, проводившейся в рамках программы ФАЙБЕКС. Было доказано, что гидроакустический прибор "Симрад СК-120" с отключенным УВР способен регистрировать отдельные особи криля на глубине в 50-60 м, пока судно находится в движении. Согласно теоретическим расчетам зона обнаружения отдельных особей может быть значительно увеличена за счет повышения мощности акустического излучения.

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DETECTION AND QUANTITATIVE ESTIMATION OF KRILL CONCENTRATIONS BY HYDROACOUSTIC INSTRUMENTS

Experience in using fish-finding hydroacoustic instruments for krill fishing in the Antarctic has indicated that the potential of these instruments for detecting commercial concentrations of krill and providing quantitative estimates of krill abundance is affected to a large extent by peculiarities in the distribution patterns of krill.

Investigations over many years have proved that krill disperses extremely non-uniformly over vast areas in the Antarctic (of an order of ten million square miles) and only forms commercial concentrations in comparatively small areas. Areas favourable for krill concentrations are characterized by whirlpools and eddies, with certain oxygen, silicon, phosphorus concentrations and other hydrological conditions. Such commercially significant areas are known in many regions of the Antarctic ocean. Due to the changeability of the environmental conditions the pattern of distribution of krill in these areas can differ between different years and seasons. In the same area at different times, krill can form large concentrations in small areas, dispersed concentrations in large areas, or be absent.

Depending on the oceanographic conditions and the biological stage, krill can stay near the surface in aggregations or groups of both large and small concentrations, or be dispersed. The size of aggregations can vary from a few to tens of meters. The width of concentrations is usually hundreds of meters. Sometimes concentrations spread over several miles and can be registered as one or a number of layers at different depths. Concentrations can vary from tens to hundreds of meters in width or more. The density of aggregations and concentrations can vary from individual specimens to thousands of specimens per cubic meter.

The depth distribution of krill is determined to a considerable extent by diurnal vertical migrations which mainly depend on light conditions. During daylight hours, krill usually stay in the middle region of the water column in groups or aggregations up to 100 m wide, sometimes up to 250 m or more. With the onset of darkness, the groups and aggregations usually come closer to the surface and disperse. However, in some areas in different seasons the pattern of krill migration can be different.

At certain times of the year, krill aggregations stay close to the surface during daylight hours. Such aggregations can be observed visually from on board ship in the shape of spots of different form and colour. The size of the spots can range from a few to hundreds of square meters. The density of surface aggregations of krill sometimes reaches tens of thousands of specimens per cubic meter. In stormy weather, surface aggregations of krill descend to deep waters, breaking into smaller aggregations and gradually dispersing.

The extremely non-uniform distribution of krill concentrations in the Antarctic ocean, coupled with the considerable instability of the concentrations and the bad weather conditions greatly impede the location of commercial concentrations and the quantitative estimation of krill abundance by hydroacoustic methods.

Experience from scouting vessel expeditions shows that the efficiency of the hydroacoustic instruments in detecting krill greatly depends on transmitter frequency. Thus, echo sounders operating at comparatively low frequencies (20-30 kHz) are much less sensitive in registering krill concentrations than sounders operating at high frequencies, e.g. 120 kHz. Records of krill concentrations by low frequency echo sounders are often indistinct, especially when the density of the krill is low, since it becomes difficult to determine the depth and vertical spread of the concentration. With the use of high-frequency echo sounders, krill concentrations are always registered distinctly and with good contrast on the echogram, and patches of different densities are well-distinguished.

It is already clear that the operating frequencies of echo sounders for krill detection should be above 50 kHz. The same is true for the operating frequencies of sonars and net sondes. However, in order to calculate the optimal operating frequencies with sufficient accuracy, it is necessary to have data on the target strength of krill and on sound attenuation in surface layers of the ocean at different frequencies.

As follows from theory, the acoustic reflectance of krill must depend strongly on frequency, especially at comparatively low frequencies (20-40 kHz). This is consistent with experimental observations [1)] in fresh water shrimp which resemble krill in form and structure. Figure 1 shows the frequency dependence of the acoustic cross-section (σ) of shrimp calculated in relation to a mean length of 4.5 cm. As can be seen from the graph, the increase in frequency from 35 kHz to 250 kHz results in an almost two fold increase of σ. At frequencies of about 50 kHz, σ becomes strongly dependent on frequency. In the frequency range from 50 to 150 kHz, this dependence becomes smoother, and on further increasing frequency, σ again increases. It is very likely that the frequency dependence of krill is similar. However, in order to be sure of this, it is necessary to carry out further investigations.

It is also necessary to undertake a detailed study of sound attenuation in the surface layers of the ocean. Early experiments in the sea have shown that sound attenuation in the surface layer is greatly influenced by the concentration of air bubbles that form under the bottom of the vessel as a result of motion and rough seas.[2)] At high frequencies, sound attenuation can be an order of magnitude lower than at low frequencies. Unfortunately, information on sound attenuation in surface layers is very scarce. It is necessary to undertake further investigations to obtain information on the frequency dependence of sound attenuation under different weather conditions and for different speeds and different types of vessels.

In considering the potential of hydroacoustic instruments for locating krill, it is important to realize the importance of solving the problem of detecting surface krill concentrations, which at certain times of the year are fairly common in some areas. As we already know, concentrations near the surface are rather difficult to detect with the existing hydroacoustic instruments and although such concentrations can be located visually, the method is inefficient. According to preliminary findings, the problem of locating surface concentrations of krill can be solved with the help of towed acoustic antennae operating upwards.

The application of towed systems is especially expedient in searching and echo-sounder surveys. The towing of antennae operating up- and downwards will make it possible to detect krill concentrations both near the surface and at depths. In addition, the towing of antennae beneath the disturbed surface layer of water must improve the operation of the hydroacoustic instrument during bad weather because of the reduction in the effects of water aeration and tossing. Another considerable advantage of towed antennae is their ease of calibration in the sea - an especially important feature for echo-surveys.

As has been mentioned above, krill are often dispersed at night and can scarcely be registered by hydroacoustic instruments, if at all. That is why the results of scouting and echo-sounder surveying performed at different times in the one location often differ considerably. Krill abundance measured in the day-time is frequently ten-fold and even a hundred-fold higher than at night when the krill are dispersed.

Control trawling and underwater observations show that fields of dispersed krill not registered hydroacoustically can occur in the day-time at depths of 200 m and more. Thus, to ensure effective scouting and echo-sounder surveying, it is very important that the hydroacoustic instruments should be capable of registering very dispersed krill, even individual specimens. It is desirable that the range of detection for an individual krill should be extended to the limit possible with the existing technical facilities.

Preliminary investigations show that detection of individual krill specimens by hydroacoustic instruments is quite possible. When making hydroacoustic investigations under the FIBEX program on board the research vessel Odissey we managed to detect krill specimens at shallow depths with the help of a Simrad echo sounder SK-120. Using the vertical location mode with maximum sensitivity and TVG switched off, this instrument distinctly registered individual krill specimens at 9 knots at depths up to 50-60 m and sometimes up to 70-80 m (Figure 2).

Tentative calculations of the limit range of detection of an individual krill (r_{max}) can be made by the following formula :

$$r_{max} \cdot 10^{0.2\ \beta r_{max}} = \frac{P_{ac} \cdot \gamma \cdot \sigma}{(4\ )^2\ J_{max}} \qquad (1)$$

where P_{ac} = acoustic power, Wt ;
γ = transducer axis concentration ;
σ = individual krill acoustic section, m^2 ;
β = space acoustic attenuation, db/m ;
J_{max} = threshold intensity of echo signals on antenna, Wt/m^2

As follows from the above formula, an increase in the range of action of a hydroacoustic instrument can be reached at the expense of a rise in the transmitted acoustic power, transducer axis concentration and sensitivity of the instrument in reception. However, the concentration coefficient is limited by the admissable transducer directivity while sensitivity in reception is limited by the level of acoustic and electric disturbance. Also, the threshold acoustic power is limited by cavitation and can be determined from the correlation

$$P_{ac} = P_{spec} \cdot S \qquad (2)$$

where P_{spec} = specific acoustic power limited by cavitation threshold, Wt/cm^2
S = active area of transmitting antenna.

In reference to the acoustic antenna of echo sounders SK-120 or EK-120 (operation frequency = 120 kHz, antenna active area S = 314 cm^2, directivity angle $\theta = 4^o$, concentration coefficient γ = 2500) submerged to

5 m (draught) and the length of transmitted pulses less than 1 msec., specific power can be accepted as 15-20 Wt/cm^2. In this case, as follows from formula (2), threshold acoustic power can be greater than 4.5 kWt.

Assuming that such a value of acoustic power is possible for a fish-finding hydroacoustic instrument [the main characteristics of which are close to those of SK-120 or EK-120 and conditions of registration of echo signals the same as aboard the Odissey ($J_{min} = 10^{-10}$ Wt/m^2 with the speed of the vessel 8-10 knots and the roughness of the sea up to force 4)], we can calculate the range of detection of an individual krill 4.5 cm long ($\sigma = 5 \cdot 10^{-6} m^2$). [4] By substituting P_{ac} = 4500 Wt, γ = 2500, $\sigma = 5 \cdot 10^{-6}$ m^2, $J_{min} = 10^{-10} Wt/m^2$ and β = 0.03 db/m in formula (1) we obtain r_{max} = 120 m.

As can be seen from the above tentative calculation, an increase in acoustic power in a high frequency echo sounder with the use of a narrow beam acoustic antenna makes it possible to considerably increase the range of detection of krill. However, expanding the range of detection by raising the acoustic axis concentration has a limit. Excessive narrowing of directivity may have a detrimental effect on the detection of dispersed krill.

As follows from our investigations [5] for detecting individual specimens with a low level of disturbance, the echo sounder directivity angle in the horizontal plane must be :

$$\theta \geqslant \frac{V_{vess}}{r \cdot f_{imp}} \qquad (3)$$

where V_{vess} = vessel speed, m/min. ;
r = depth of registration of the item, m ;
f_{imp} = transmission repetition frequency, imp/min.

This condition ensures reliable reception and registration by the recorder and integrator of no less than one echo signal from an individual krill. As an example, we have calculated by formula (3) directivity angles required for detecting an individual krill at different depths with the echo sounder operating in the range of 125 m (f_{imp} = 96 imp/min) and 250 m (f_{imp} = 48 imp/min). The vessel speed was assumed to be 10 knots (V_{vess} = 308.7 m/min). The graph obtained from the results of these calucations is shown in Figure 3.

As follows from the graph, the detection of krill at shallow depths requires rather wide directivity angles of the transducer. They would be especially large with the use of small-scale ranges. Therefore when operating with a narrow beam antenna echo sounder there may be blanks in the registration of krill at shallow depths. In a rough sea, these blanks become more frequent. This impedes detection of dispersed krill and decreases the reliability of the estimation of their density by integrator readings. This situation can be partially reversed when monitoring dispersed krill at shallow depths by using a comparatively wide beam antenna and the large scale range of the recorder.

Blanks in registration and errors in determining density and abundance of dispersed krill can be removed if the operation is performed at a low speed or with the vessel adrift. In such cases, the range of action of the hydroacoustic instrument becomes uninterrupted and the recorder and integrator register all the krill along the course of the vessel. By making control measurements of density at a low speed or with the vessel adrift and by comparing them with the measurements made at full speed, it is possible to introduce certain corrections into the calculations of density and abundance of dispersed krill from the echo sounders.

In summary, we can see that the limited capabilities of the existing hydroacoustic instruments in detecting dispersed and surface concentrations of krill may lead to considerable underestimates of krill biomass in the areas surveyed. In order to ensure accurate estimation of dispersed krill and presurface concentrations it is necessary to further improve echo-sounder survey techniques.

Of equal importance is the development of the theoretical methods for estimating biomass, and in particular for verifying the principles governing sound scattering in dense concentrations. So far we do not know the limits of application of Rayleigh's principles concerning scattering which underlie the formula for determining the density of krill concentrations registered by hydroacoustic instruments.

Our theoretical investigations [6,7] show that with the use of high frequency narrow beam hydroacoustic instruments, considerable interference in Rayleigh's relationships due to coherent and multiple scattering should be expected only in very high density krill concentrations in the order of thousands of specimens per cubic meter. It is clear that only experimental investigations can reveal the real importance of coherent and multiple scattering and acoustic attenuation for dense krill concentrations and introduce the required alterations in the formula for calculating their density. The preliminary experiments show that such work can apparently be done on experimentally caged krill concentrations.

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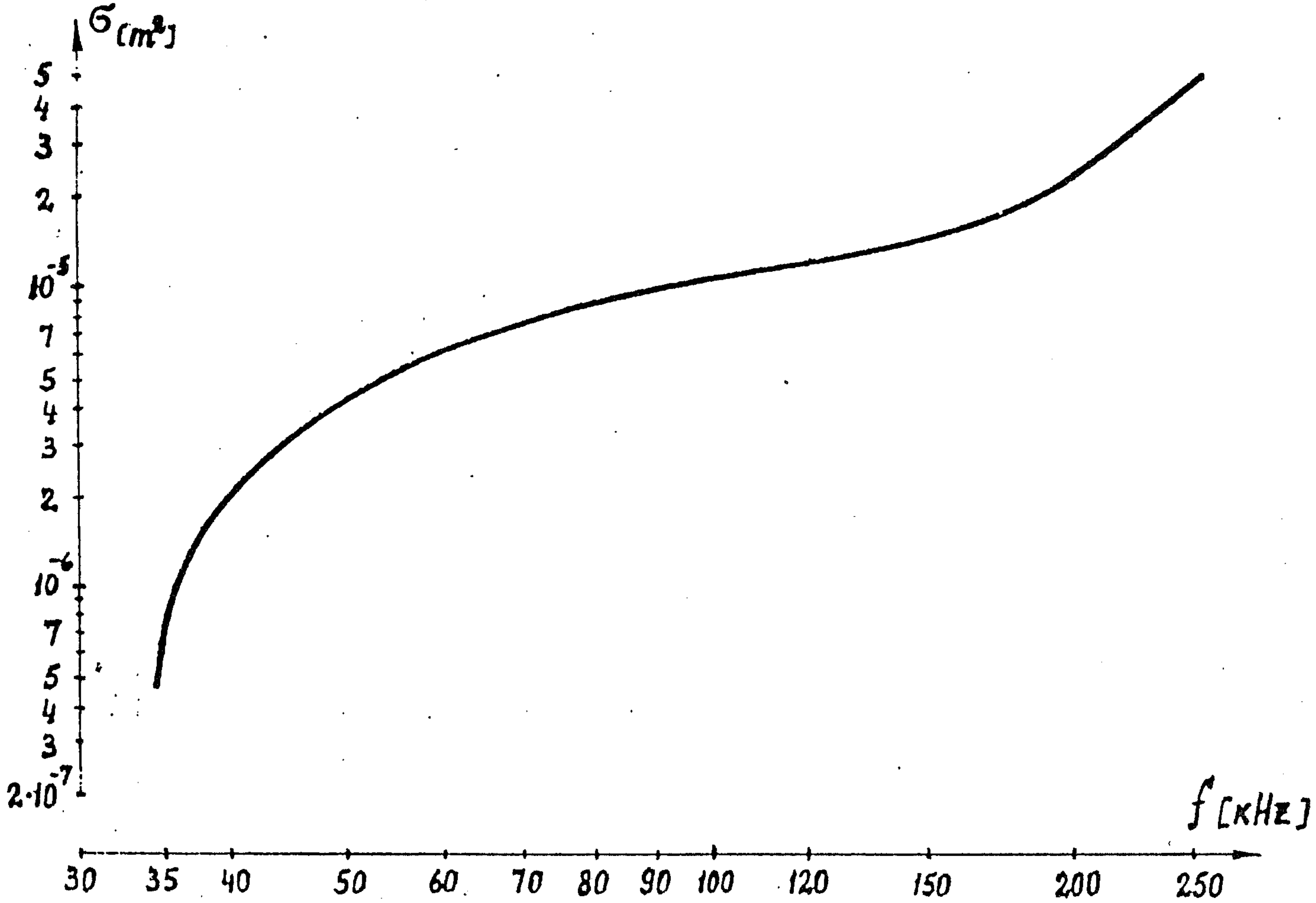
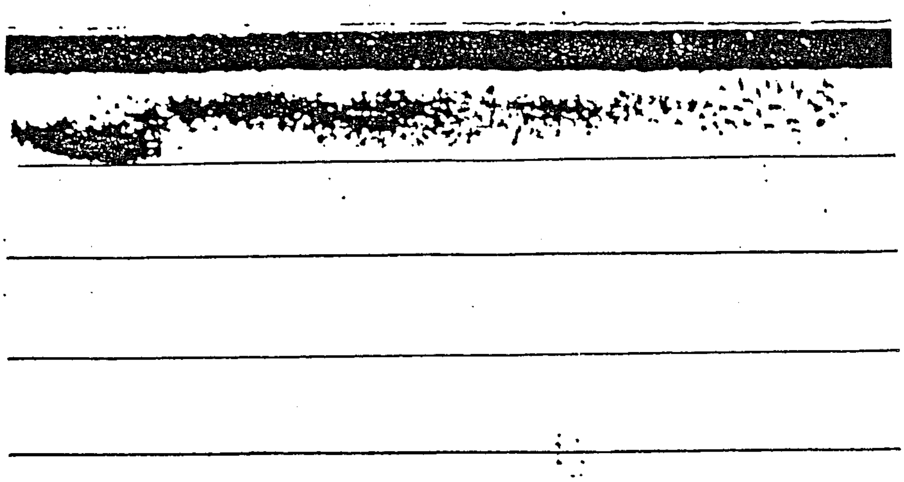


Figure 1 Dependence of freshwater shrimp acoustic section on frequency (shrimp length - 4.5 cm).

a/.



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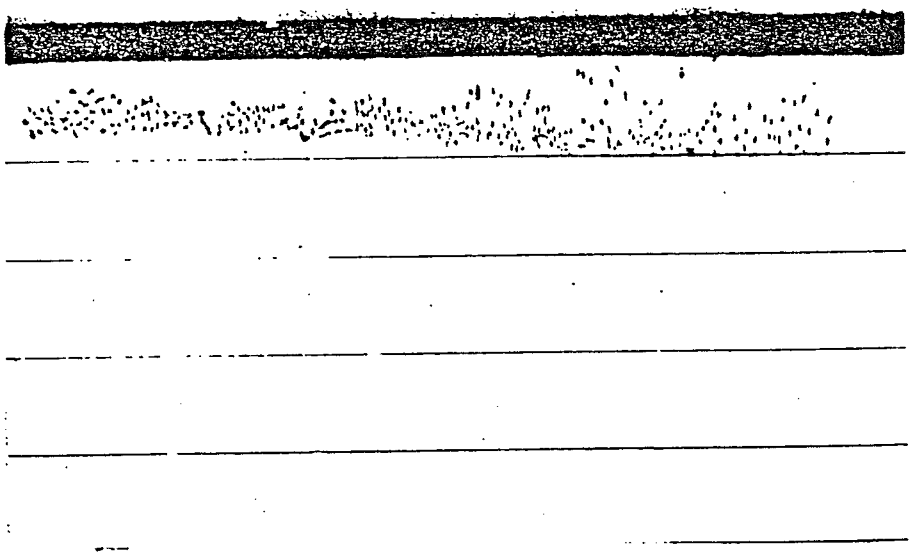

Figure 2 Echo gram of dispersed krill by SK-120

a) at low speed of the vessel

b) at a speed of 9 knots

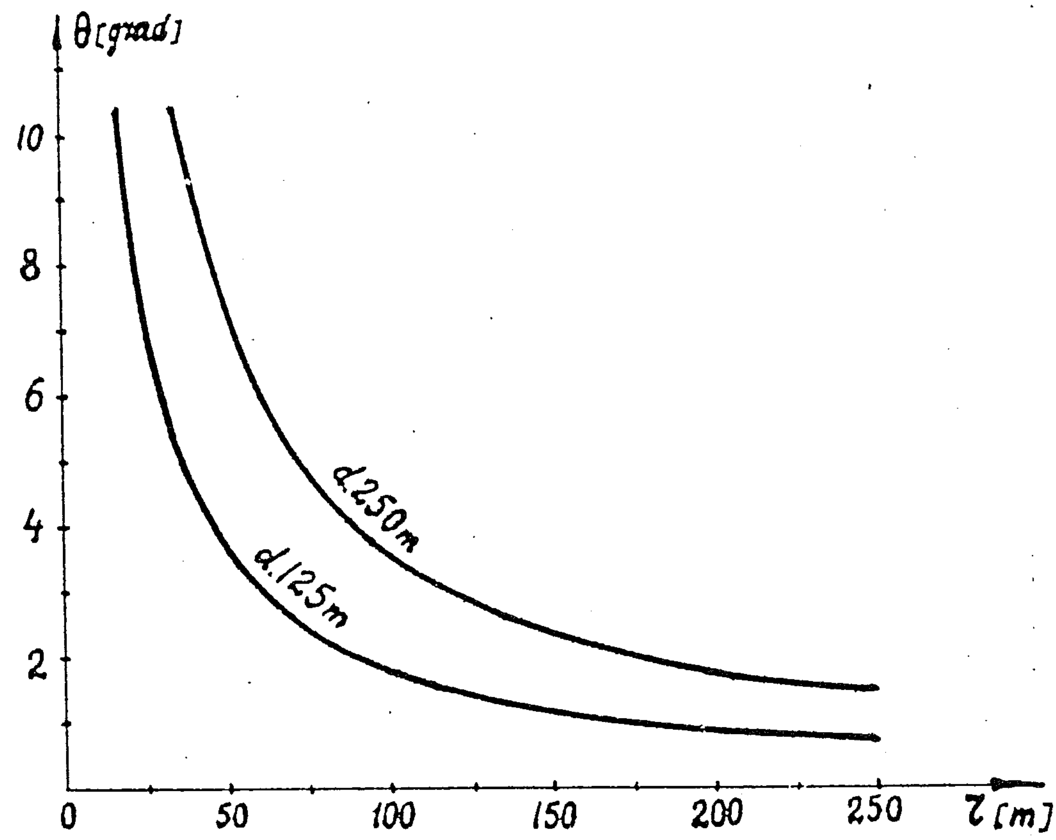

Figure 3 Dependence of the depth of detection of individual krill for different ranges of the recorder on transducer threshold directivity angle.

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