MEASUREMENTS OF DIFFERENCES IN THE TARGET STRENGTH OF ANTARCTIC KRILL (*EUPHAUSIA SUPERBA*) SWARMS AT 38 KHZ AND 120 KHZ

I. Hampton*

Abstract

Differences in the target strength of adult (36 to 60 mm) Antarctic krill (*Euphausia superba*) at 38 and 120 kHz have been inferred from differences in the mean back-scattering strength of swarms simultaneously insonified at these two frequencies in studies off the South Orkneys and Elephant Island in March 1990. Back-scattering strengths at 120 kHz ran consistently about 7 dB higher than at 38 kHz, a difference which was regarded as too large to be explained by possible experimental error, and which was therefore attributed to real differences in average target strength at these two frequencies. The results are in good agreement with recent experimental work on the target strength of encaged *E. superba* at 38 and 120 kHz but are in major conflict with the 120 kHz - to - 50 kHz target strength conversion factor used at the Post-FIBEX Acoustic Workshop in 1984.

Résumé

Les différences d'intensité de réponse acoustique du krill antarctique (*Euphausia superba*) adulte (36 à 60 mm) à 38 et 120 kHz ont été inférées à partir des différences d'intensité moyenne de rétrodiffusion d'essaims insonifiés simultanément à ces deux fréquences dans des études au large des Orcades du Sud et de l'île Eléphant en mars 1990. A 120 kHz, les intensités de rétrodiffusion étaient constamment de 7 dB plus élevées qu'à 38 kHz; cette différence, considérée comme étant trop importante pour pouvoir s'expliquer par une erreur possible d'expérimentation, doit donc être attribuée à des différences réelles dans la réponse acoustique moyenne à ces deux fréquences. Les résultats concordent bien avec de récents travaux expérimentaux sur la réponse acoustique d'*E. superba* en enceinte à 38 et 120 kHz, mais sont en contradiction totale avec le facteur de conversion de la réponse acoustique de 120 kHz-à-50kHz utilisé à l'Atelier acoustique Post-FIBEX de 1984.

Резюме

Различия в силе акустической цели взрослого (30-60 мм) антарктического криля (*Euphausia superba*) при частоте в 38 и 120 кГц были определены по различиям в средней силе обратного акустического рассеяния скоплений, одновременно исследуемых эхолотом, работающим на данных частотах, в ходе исследований криля в районе Южных Оркнейских островов и острова Элефант в марте 1990 г. Величины силы обратного акустического рассеяния при

* Sea Fisheries Research Institute, Private Bag X2, Roggebaai, 8012, South Africa

частоте в 120кГц постоянно превышали величины, полученные при частоте в 38 кГц, приблизительно на 7 дБ. Эта разница была признана слишком значительной для того, чтобы отнести ее на счет возможных погрешностей в эксперименте, поэтому она была признана следствием реальных различий в средней силе акустической цели при этих двух частотах. Результаты хорошо согласуются с теми, которые были получены недавно в ходе экспериментальных работ по определению силы акустической цели помещенного в садок криля *E. superba* при частотах в 38 и 120 кГц, но в значительной мере противоречат коэффициенту пересчета силы акустической цели 120-50 кГц, использованному на Рабочем семинаре по акустике, проведенном в 1984 г. по завершении программы FIBEX.

Resumen

De los estudios realizados cerca de las islas Elefante y Orcadas del Sur durante marzo de 1990, se dedujeron las diferencias que ocurren en la potencia del blanco del krill antártico adulto (36-60 mm) (*Euphausia superba*), al emplear frecuencias de 38 y 120 kHz y considerando las diferencias en la potencia media de retrodispersión obtenida de los cardúmenes sondeados simultáneamente en ambas. Las potencias de retrodispersión a 120 kHz permanecieron constantes alrededor de 7 dB más altos que las obtenidas a 38 kHz, diferencia que se consideró demasiado grande para poder interpretarla como un error experimental, y por lo tanto se atribuyó a diferencias reales en la potencia promedio del blanco que ocurren en estas frecuencias. Los resultados concuerdan con un trabajo experimental reciente sobre la potencia del blanco de *E. superba* en captividad, donde se emplearon frecuencias de 38 y 120 kHz pero existe una gran disparidad con el factor de conversión de la potencia del blanco de 120 kHz a 50 kHz utilizado en el taller acústico realizado con posterioridad a FIBEX en 1984.

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1. INTRODUCTION

Acoustic surveys of krill (*Euphausia superba*) abundance have commonly been conducted at echosounder frequencies of between 50 and 200 kHz, with 120 kHz being probably the most common frequency (Miller and Hampton, 1989). Knowledge of the frequency-dependence of krill target strength, and in particular, of the relation between target strength at 120 kHz and that at other commonly used frequencies, is therefore necessary for comparing and combining abundance estimates made at different frequencies.

To date the most controlled comparison of the frequency-dependence of *E. superba* target strength is one made by Foote *et al.* (1990) on live animals at South Georgia. Target strengths at 38 and 120 kHz were estimated by measuring the strength of the back-scatter from aggregations of encaged animals which varied in mean length from 30 to 39 mm. Calculated target strengths at 120 kHz were some dB higher than at 38 kHz, in general agreement with predictions from a fluid sphere theoretical model of Greenlaw (1979).

The present study was carried out on wild *E. superba* aggregations encountered off Coronation Island, South Orkneys and Elephant Island, South Shetlands, in March 1990 from

RS *Africana*, a 78-m research stern-trawler of the Sea Fisheries Research Institute, Cape Town, South Africa. The study was part of a broader investigation into krill aggregating and distribution patterns in these two regions.

Data were collected between 7 and 10 March from the edge of the shelf to the north-west of Coronation Island, and on 16 March from the north-western shelf edge of Elephant Island. Aggregations were simultaneously insonified at 38 and 120 kHz. Differences in average target strength at these two frequencies were computed from differences in the average strength of the back-scatter between the same vertical and horizontal limits.

2. MATERIALS AND METHODS

Simrad EKS-38 and EKS-120 echosounders were used. The transducers were hull-mounted 6 m below the surface, some 40 cm apart on the same stabilized platform. The combined Source Level and Voltage Receiving Sensitivity (SL + VRS) for both sounders was measured to within an estimated ± 0.5 dB by calibration with a standard copper sphere (Foote, 1983) immediately prior to the cruise. These values and other relevant calibration data for each sounder are shown in Table 1. The SL + VRS value for each sounder agreed to better than 1 dB with figures obtained by similar calibrations of these two sounders over the past three years. Spot checks on SL and VRS made before, during and after the cruise with a built-in hydrophone monitor indicated that the sounders were each probably stable to within 1 dB during the cruise.

The sounders were synchronized with each other and the echo signals fed into a dual-input, custom-built digital integrator and storage system where multi-channel echo-integration could be performed (Anon., 1986). In one system (System A), signals exceeding a pre-set threshold were integrated in real time in 5-m channels while in the other (System B) the entire echo-envelope, if exceeding the same threshold, was stored and subsequently integrated off-line. Integrations were restricted to the upper 100 m, the maximum range of the EKS-120 internal TVG (Time-Varied-Gain).

Corrections for TVG imperfections were applied at both frequencies, using measurements of receiver gain corresponding to 5-m depth channels between 5 and 100 m. For each integration interval the correction was taken as that applicable to the 5-m channel in which the acoustic back-scatter during the interval was strongest. The corrections were generally of the order of ± 1 dB, ranging from -1.40 dB at 35 m for the EKS-38 to +1.38 dB at 35 m for the EKS-120. The residual TVG-related error in back-scattering strength after correction was considered to be less than ± 0.5 dB at both frequencies.

Back-scatter comparisons, measured in terms of the Mean Surface Back-Scattering Strength (MSBS) were restricted to integration intervals where substantial and unmistakeable krill targets were detected. Initially the 38 kHz signal was integrated through System A and the 120 kHz signal through System B. Later, the inputs were interchanged to balance out the effect of possible differences in the two integrator systems. One integration was done between 5 and 100 m over an interval in which no krill were evident on either sounder in the upper 100 m, to check the level and frequency-dependence of the noise background.

Three aimed trawls were made with a commercial midwater trawl in the general area of the Coronation Island study, to identify targets and collect length distribution information. Two such trawls were also made in the Elephant Island study region.

3. RESULTS

Krill in both areas were generally found in discrete swarms which were clearly recorded to at least 200 m on both sounders (e.g., Figures 1 and 2). Fifteen comparable integration intervals were selected from the Coronation Island area and five from the Elephant Island region. The intervals varied in duration but were typically about 15 minutes long. Most intervals contained between 1 000 and 1 500 pings. In all, about 200 discrete swarms were recognizable in the former data set and about 50 in the latter.

The TVG-corrected MSBS values at 38 and 120 kHz and the differences between them (Δ MSBS) are shown for both sets of intervals in Table 2, and are plotted in Figure 3. The frequency change-over point is shown in both. Table 2 also shows the noise background at both frequencies (Interval 470).

It can be seen from Figure 3 that the MSBS values at the two frequencies track each other extremely well, with the 120 kHz values running some 7 dB higher throughout. The mean difference in MSBS (Δ MSBS), computed by averaging the anti-logs of the Δ MSBS values, was 7.1 dB off Coronation Island and 6.9 dB off Elephant Island. The noise background was some 8 dB below the lowest MSBS value, and furthermore did not exhibit the same frequency-dependence as the data from the krill, so it can be discounted as a source of error. Similarly, there was no noticeable difference in Δ MSBS when the frequencies were interchanged, removing any fear that the differences were an artefact of differences in the two integration systems.

Length frequencies for the three samples taken off Coronation Island are shown in Figure 4, and for the two Elephant Island samples in Figure 5. Mean lengths in the two area were 48.75 and 45.98 mm respectively.

4. DISCUSSION

The prime concern is whether the differences in back-scattering strength at the two frequencies are due to a real difference in average target strength at these frequencies, or to some experimental artefact. Because of the closeness of the transducers, essentially the same targets would have been insonified at both frequencies (ignoring random differences caused by any small time delay between firing of the two transmitters), so differences from this sources, which would in any event have been random, can be discounted. The only other artefact could have come from a gross error in the calibration of one or both of the sounders. However, in view of the accuracy achievable in sphere calibration of the SL + VRS parameter (conservatively ± 0.5 dB), the consistency of the hydrophone spot checks, and the agreement with previous sphere calibrations of the sounders (see Methods section), a corss-calibration error as large as 7 dB is considered to be highly unlikely. Even allowing for an error of 0.5 dB in the estimation of SL + VRS, and for the same error in the equivalent beam factor and in the TVG correction, gives an upper limit of only 1.5 dB for error in each system and a maximum calibration error of 3.0 dB in any comparison between them. The MSBS differences obtained can therefore be regarded as significant, indicative of a real target strength difference at the two frequencies.

The MSBS differences are in the same sense of the same order as those obtained by Mathisen and Macaulay (1983) in their investigations on the back-scattering from swarms of *E. superba* at 50 and 120 kHz, which suggests a target strength some 3 dB higher at 120 kHz than at 50 kHz. Furthermore, the differences are in good agreement with Foote *et al.*'s (1990) recent results from their cage experiments on *E. superba* target strength at 38 and 120 kHz. For their largest animals (mean length 39.4 mm), which were the closest in size to those in the present study, they obtained a mean target strength 8.2 dB higher at 120 kHz than at 38 kHz (Event 17, their Table I). Their computed theoretical difference for animals of this size, which they obtained by substituting their own sound-speed and density-contrast measurements into Greenlaw's (1979) fluid sphere scattering cross-section model, was 4.2 dB (Event 17, their Table III).

The increase in target strength with frequency is however in major disagreement with Kristensen's (1983) target strength spectrum for 40 mm tethered euphausiids in dorsal aspect, which shows a decrease in target strength of some 5 to 6 dB as frequency increases from 38 to 120 kHz (see Miller and Hampton, 1989, Figure 16). Kristensen's spectrum was used at the Post-FIBEX (First International Biomass Experiment) Acoustic Workshop in 1984 (BIOMASS, 1986) to develop a target strength/length relationship at 50 kHz from the one used for 120 kHz data. The result was to raise target strengths at 50 kHz by 5.5 dB compared to those at 120 kHz. Use of the present data, assuming that target strength differences between 38 and 50 kHz are small, would have resulted in all FIBEX density estimates made at 50 kHz being raised by 12.5 dB, an increase of 17.7 fold, amply demonstrating the importance of obtaining reliable *in situ* information on krill target strength spectra.

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Table 1: Calibration data for EKS-38 and EKS-120 echosounders.

	38 kHz	120 kHz
SL + VRS (dB)	128.3	115.8
Pulse duration (ms)	0.90	1.00
Equivalent ideal beam factor (dB)	-19.6*	-18.0*
Absorption coefficient (dB/km)	10.5	40.0

* From manufacturer's specifications

Table 2: Mean surface back-scattering strength at 38 kHz (MSBS-38) and 120 kHz (MSBS-120), and the difference between them (MSBS) for all intervals.

Interval Number	MSBS-38 (dB)	MSBS-120 (dB)	MSBS (dB)
Coronation Island			
269	-46.1	-40.7	5.4
271	-55.3	-48.4	6.9
272	-55.1	-47.9	7.2
273	-47.7	40.7	7.0
274	-47.2	-40.9	6.3
275	-44.1	-37.5	6.6
276	-54.7	-48.1	6.6
277	-56.0	-47.4	8.6
279	-52.7	-45.0	7.7
280	-44.8	-37.7	7.1
281	-46.8	-40.0	6.8
282	-50.4	-43.7	6.7
Inputs Interchanged			
283	-50.5	-42.6	7.9
290	-46.4	-37.7	8.7
291	-46.8	-39.4	7.4
Mean			7.1
Elephant Island			
442	-44.7	-37.3	7.4
443	-54.9	-49.1	5.8
447	-51.5	-45.8	5.7
448	-53.4	-45.7	7.7
466	-55.8	-47.4	8.4
Mean			6.9
470 (Noise)	-63.2	-64.8	-1.6

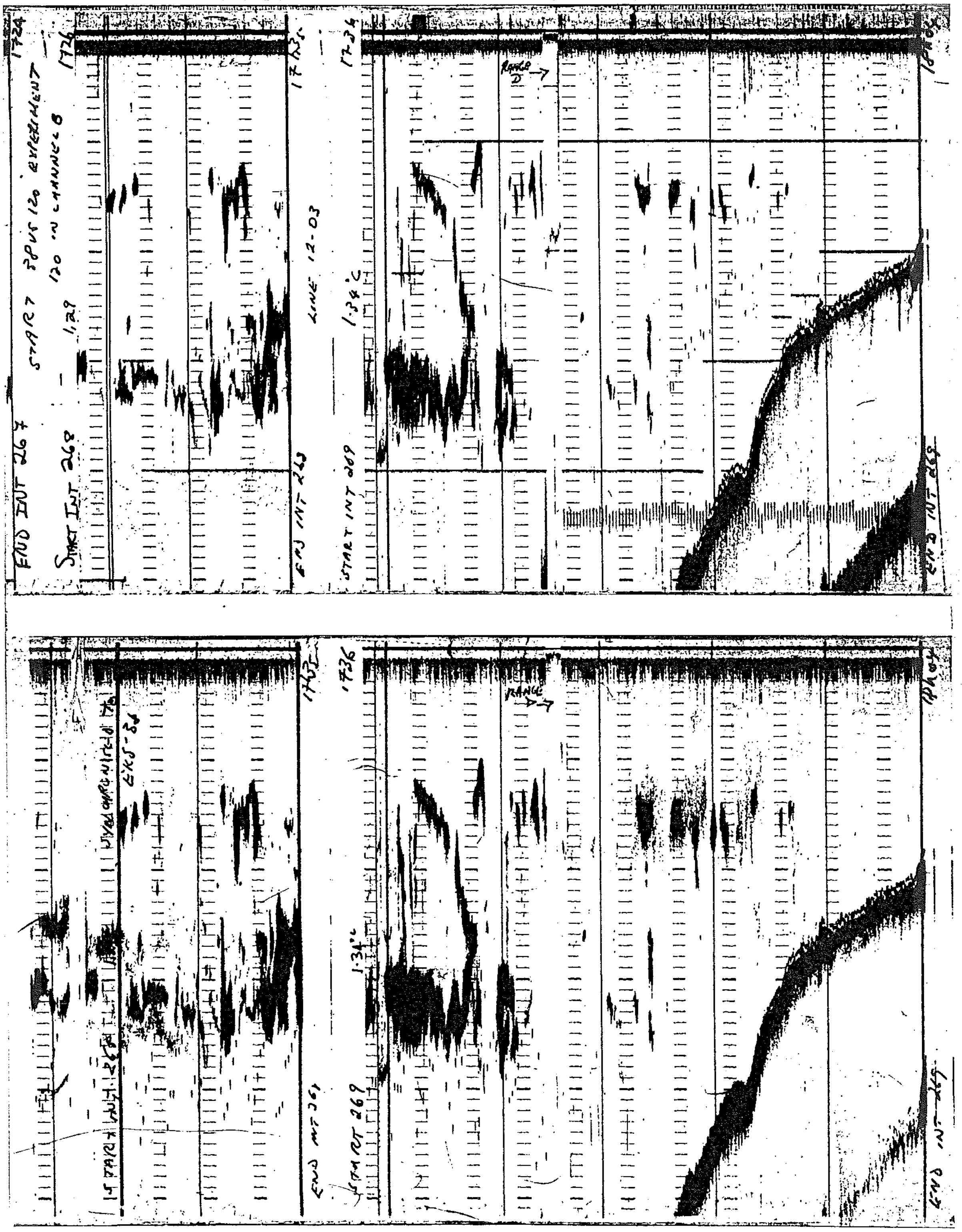

Figure 1: Echosounder recordings of krill swarms off Coronation Island made at 38 kHz (top) and 120 kHz (bottom). The distance between vertical lines is 1 n. mile.

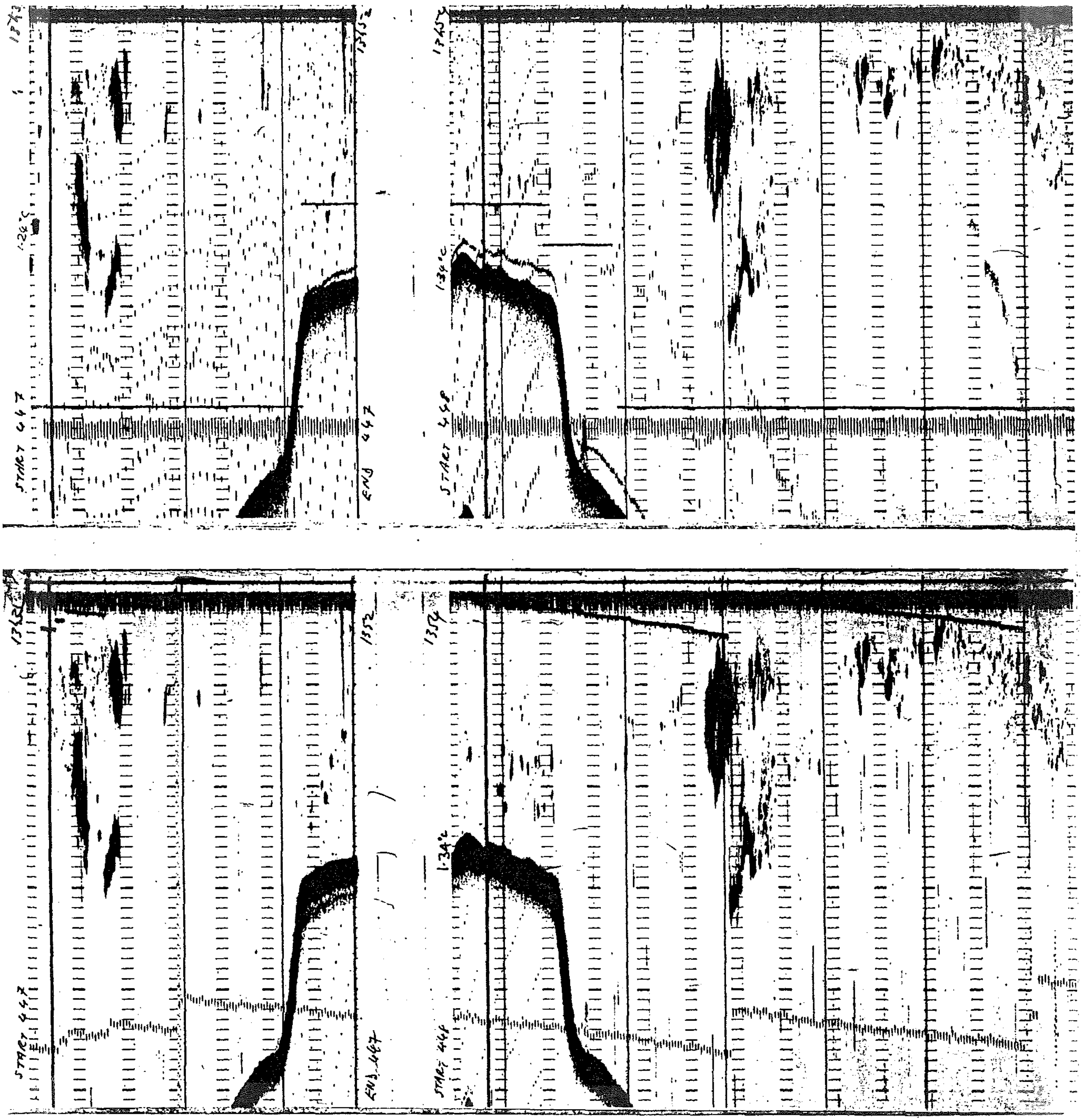

Figure 2: Echosounder recording of krill swarms off Elephant Island made at 38 kHz (top) and 120 kHz (bottom). The distance between vertical lines is 1 n. mile.

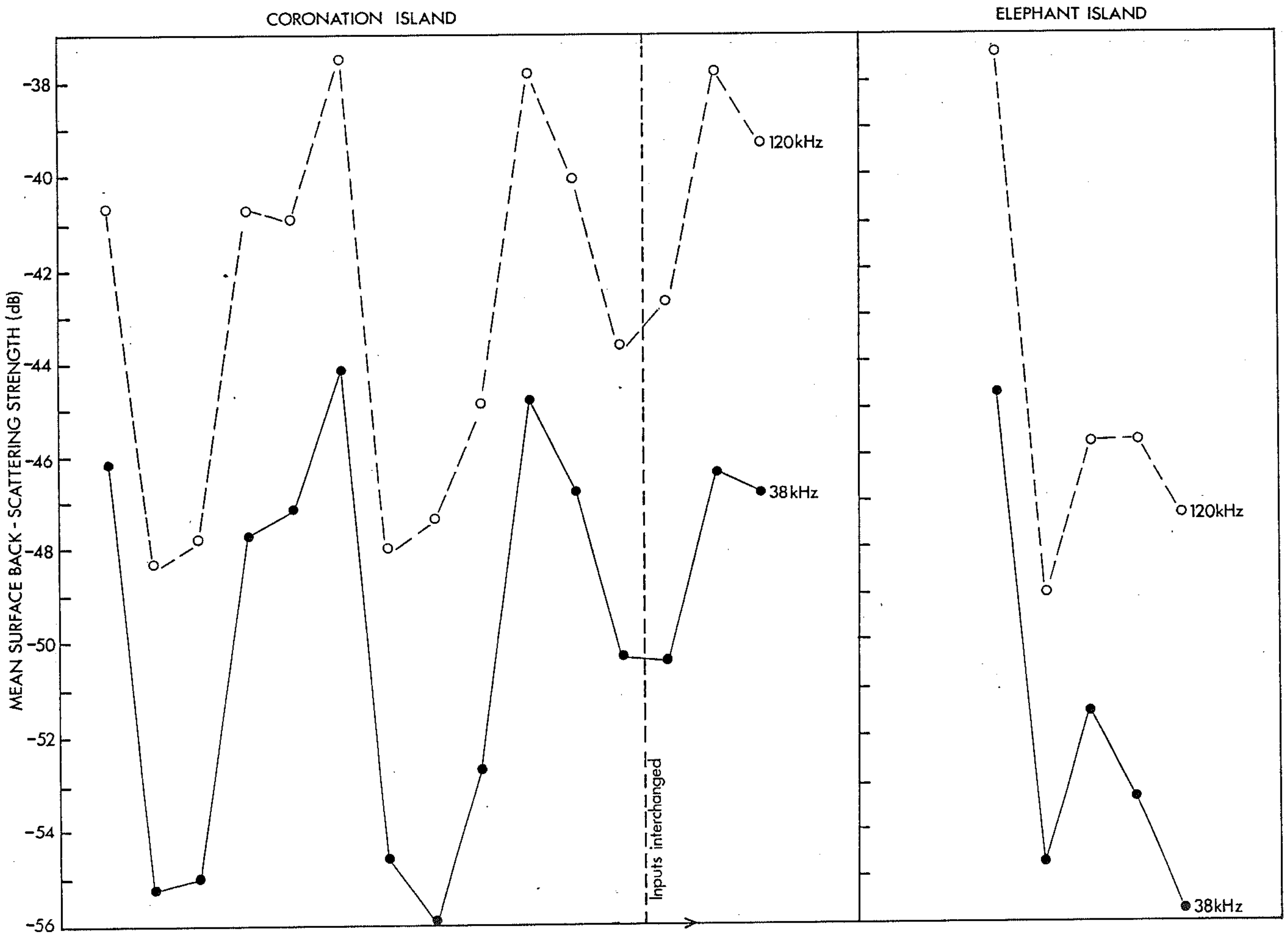

Figure 3: MSBS values at 38 and 120 kHz for all intervals. The dashed vertical line indicates the point at which the frequencies were interchanged between the two integration systems.

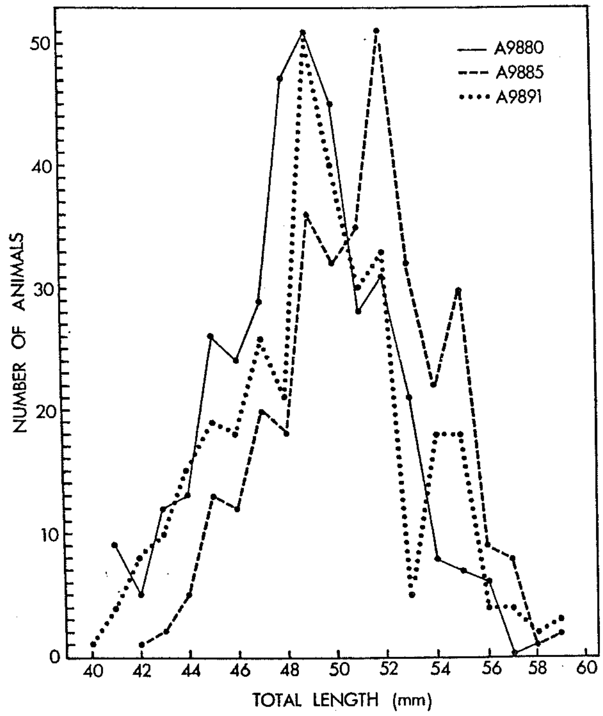

Figure 4: Length distributions of krill taken in Coronation Island trawls.

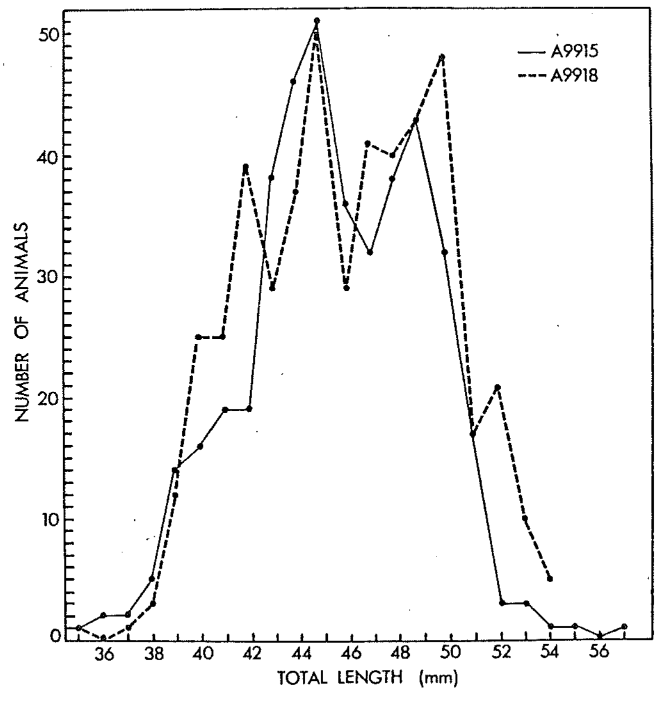

Figure 5: Length distributions of krill taken in Elephant Island trawls.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras