THE MORPHOLOGICAL FEATURES OF A SUPER SWARM OF KRILL, *Euphausia superba*

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Abstract: During the R.V. MELVILLE (USA) Cruise in 1981, a dense aggregation of krill near the Elephant Island was mapped acoustically. The data acquisition system consisted of a Braincon fin equipped with 2 downward oriented transducers operating on 50 kHz and 120 kHz, respectively. The signals were recorded on F-M seven track taperecorder and integrated with one minute intervals and by 10 m depth strata down to at 190–200 m depth. The results were expressed in dB/m^3 or dB/m^2 surface area.

In general the edges of the aggregation appeared well defined with a steeper gradient on the exposed than on the lee side. The vertical distribution at the edges presented a wedge or lens shaped picture which usually was located in 30–40 m in depth but could also be found toward the bottom. In the central part density was uniformly high from 30 m and down to 140–150 m depth. The structures were constantly shifting with deformation and reformation obviously related to the ongoing vital processes of the individual krill. Some differences were noted in the results derived by the two frequencies 120 kHz and 50 kHz.

1. Introduction

During the austral summer of 1980/81 the research ship R.V. MELVILLE from the Scripp's Institution of Oceanography in La Jolla, California operated in the Scotia Sea–Weddell Sea area conducting oceanographic and biological studies. One segment of the cruise, Leg Vulcan 7 extending from February 19 through March 31 was devoted in part to an acoustic assessment of krill including distributional patterns with emphasis on aggregations of krill, their configurations and densities.

The nomenclature and definitions of various types of aggregations of krill are complicated and not universally agreed upon. Thus MAUCHLINE (1980) proposed a classification ranging from a simple aggregation through patch to shoal which contains elements like swarm and school. A more colloquial term is super swarm which denotes large cohesive groups of individuals of krill. But it is rather difficult to reach agreement on terminology before all types of aggregation have been described and their origin and permanency studied. In this paper super swarms signify unusually large aggregations of krill present continuoulsy for several days. Their rare occurrence and large biomass distinguishes them from the frequently occurring schools which might only represent an ephemeral stage in a diel migration cycle (EVERSON, 1982). Clearly a mere description is only the first step in explaining origin and biological functions of such large and high density concentrations of krill, encompassing both immature and mature specimens.

2. Data Aquisition Systems and Analysis

The swarms to be reported on here were observed in 1982 on the north side of the Elephant Island, one encountered at 60°56.2′S, 55°15.9′W on March 7–8 and the other at 60°57.1′S, 55°52.3′W (Fig. 1). The dimensions and total biomass contained in these swarms are described elsewhere (MACAULAY *et al.*, 1983). However the presence of a large Soviet fishing fleet comprising 30–35 vessels in the 4–5000 ton class for a period of at least 6 weeks with a total estimated catch of at least 250000 metric tons (GUZMAN, pers. commun.) testifies to the universal occurrence of krill aggregations in this area. This was amply demonstrated by the German expeditions in 1975/76 and 1977/78 (FREYTAG, 1978; FISCHER, 1979).

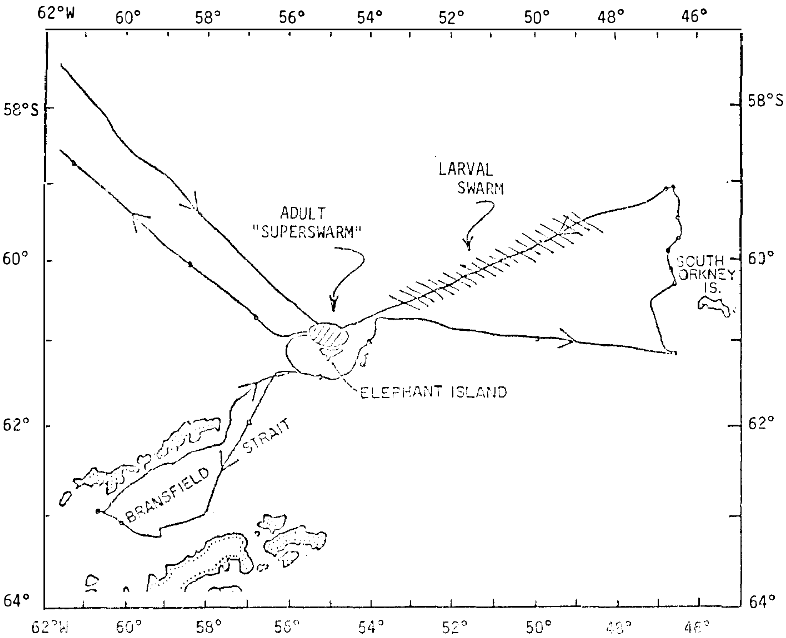


Fig. 1. Cruise track, Vulcan leg 7. Hatched region north of Elephant Island is the region of the "Superswarm" (adult krill) investigations (see text). Hatched region along track between South Orkney Island and Elephant Island is the region of the larval swarm (also see text).

The data acquisition system consisted of a 4-ft v-fin (Braincon Inc.) towed behind the ship at about 10 m depth with an armored conductive cable. Jerks caused by wave action were buffered by a system of elastic shock absorbing cords. The fin contained three transducers, one side-looking operating at 105 kHz and two downward looking operating at 120 kHz and 50 kHz respectively (Fig. 2). The received signals were recorded on F-M seven track taperecorder and integrated with one minute intervals and by 10 m depth strata down to 190–200 m depth. The results were expressed in dB/m^3 per depth stratum or dB/m^2 surface area. For a more detailed description of system parameters and analytical procedures see (MACAULAY *et al.*, 1983).

This method of reporting was agreed upon by the Working Party on Krill Abundance (Anonymous, 1980) as a relative measure of abundance proportional to krill bio-

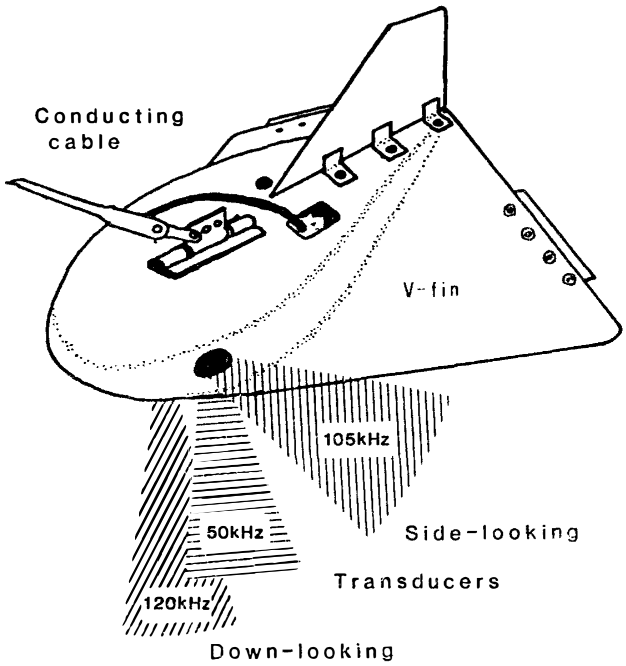


Fig. 2. Three frequency towed array.

mass and which can be scaled into absolute numbers once the proper *TS* of krill *in vitro* has been agreed upon.

3. The Internal Structure of a Super Swarm of Krill

It is doubtful that one can develop an average behavior norm or pattern of a krill swarm. Dense aggregations of fast swimming animals cannot be expected to portray a static picture. A swarm is more like a fog bank which constantly changes form due to small shift in the wind, the fog lifts or settles, become denser or rarefies constantly. What can be done is to describe observed diel patterns in dense or light aggregations, which may contain only mature or immature animals or a mixture of size groups.

The following description is based on data acquired with the two mentioned frequencies, 50 kHz and 120 kHz respectively. An over-all picture is illustrated in Fig. 3 where the top half represents a transect through a dense school of primarily mature and large krill while the bottom part is from a transect taken two weeks later when the schools had moved away from the central part of the Elephant Island and contained mixed size groups (BRINTON and ANTEZANA, 1982).

Biomass is expressed in kg/m^2 surface area by introducing a value for target strength as a function of both sounder frequency and length of the animals. The equations used were those agreed upon at the Acoustic Workshop in Hamburg in Sept./Oct. 1981 (HAMPTON, 1983). For a krill 45 mm long, the corresponding values are:

$$50\,\text{kHz:}\quad TS = -100.82 + 20.0\log_{10}45 = -67.76\,\text{dB},$$

$$120\,\text{kHz:}\quad TS = -97.2 + 20.0\log_{10}45 = -64.14\,\text{dB}.$$

Thus assessment with a 120 kHz sounder would be expected to yield a target strength of about 3 dB higher values than for a 50 kHz one. This difference is invari-

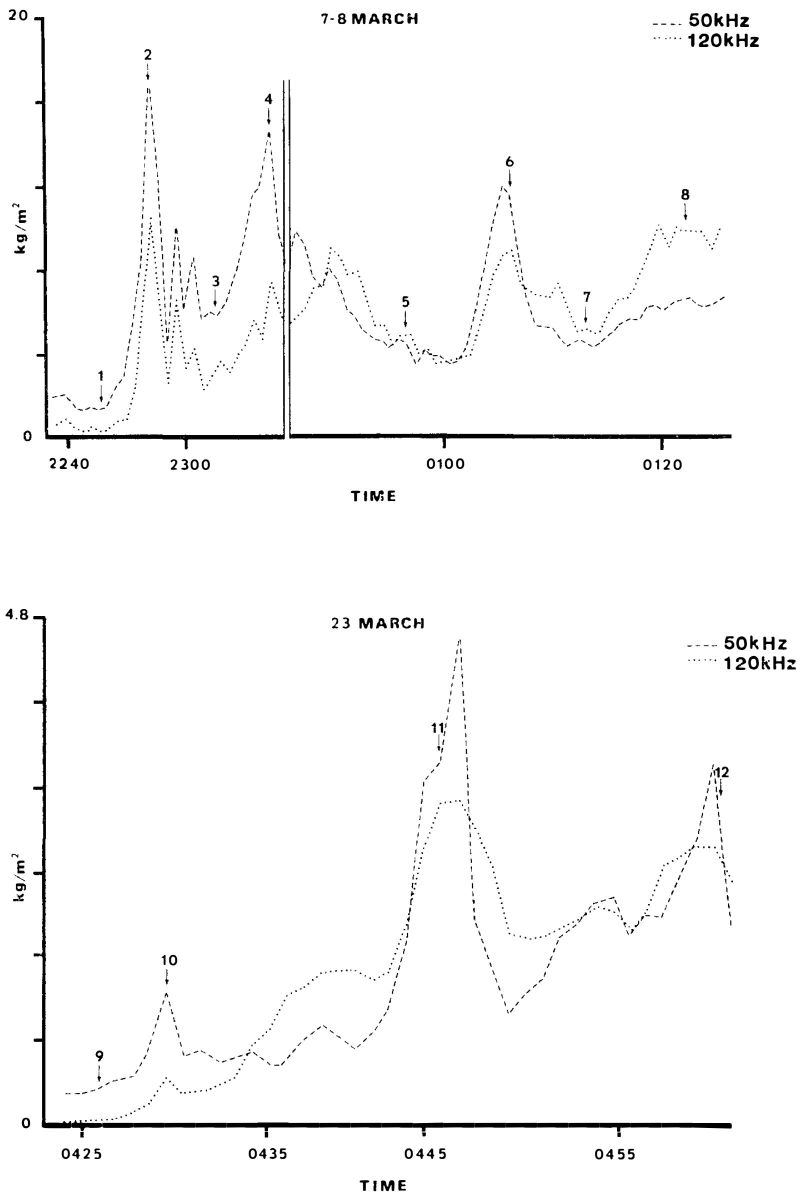


Fig. 3. Total biomass estimates expressed in kg/m² surface area. Time is GMT. Conversion of mean volume back scattering $\bar{S}_v$ to absolute values is discussed in the text. Numerals indicate position where density profiles were made.

ant to length in their present form, which probably is not correct, and the given values should therefore be considered preliminary ones.

As would be expected the two curves track each other closely on both dates. If the insonified biomass is estimated by integrating the two curves, both estimates are very close in spite of the local variability seen between the two curves. Some possible reasons for this will be discussed later. However, it may be concluded that a frequency range in the data acquistition systems extending from 50 to 120 kHz can be used in general survey work, although there are specific situations where factors like high densities, distribution over wide depth ranges, and size composition must govern the final choice of sounder frequency.

The edges of the dense aggregation surveyed on March 7–8 were distinct with a density gradient rising from minimal ambient values to the maximum value observed in 5 minutes or less than 1 km outsailed distance. As expected there was a slower gradient with the lesser concentration encountered on March 23. The observed maxima and minima clearly represented transient features, but even the peak value of 16 kg biomass/m^2

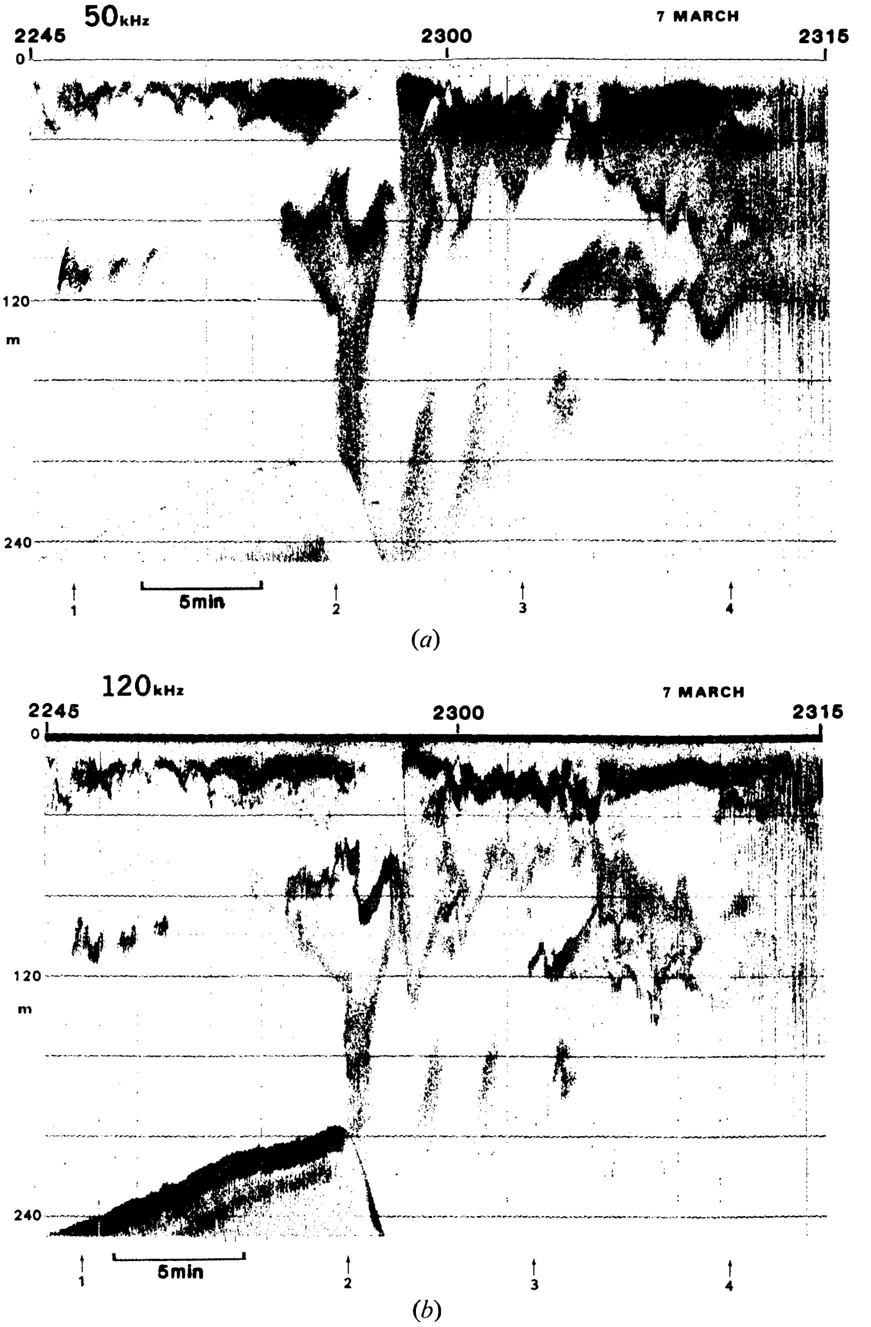


Fig. 4. Echograms recorded on March 7, 1981 from 2245 to 2315 (GMT). Positions of four density profiles are marked with the numerals 1, 2, 3, and 4. Top echogram from a 50 kHz sounder (a). Bottom echogram from a 120 kHz sounder (b).

surface area distributed evenly over the upper 100 m water masses depth range represented only 160 g biomass/m^3 which is rather low compared with other observed values on densities given in the published literature (EVERSON, 1977). An average value for the entire track line would only be half of this value for this particular swarm.

A more exact description can be made than one based on average values since the material permits analysis of the integrated values for a time unit of only 1 minute and with contiguous depth strata, each 10 m wide. The locations where density profiles were prepared are marked with consecutive numbers in Fig. 3 and repeated again on Fig. 4 which represents an echogram acquired on March 7 extending from 2245 to 2315 GMT, and the local time can be obtained by subtracting 4 hours from GMT.

Although the upper 10 m of the water column was not insonified, this swarm was not detectable at the surface so it is unlikely that many details were missed in the echograms. Two features are noteworthy. First, the estimated peak biomass value occurred at Profile 2, where the krill still appeared in discontinuous layers, more resembling the daytime dense but isolated krill school recorded in this area and elsewhere. Second, at this point the krill extended from direct contact with the bottom at 200–240 m depth and upward for 140–160 m. But as one entered into the continuous distribution (Profile 4) there were sign of multiple scattering from this dense layer extending from about 10 to 120 m depth.

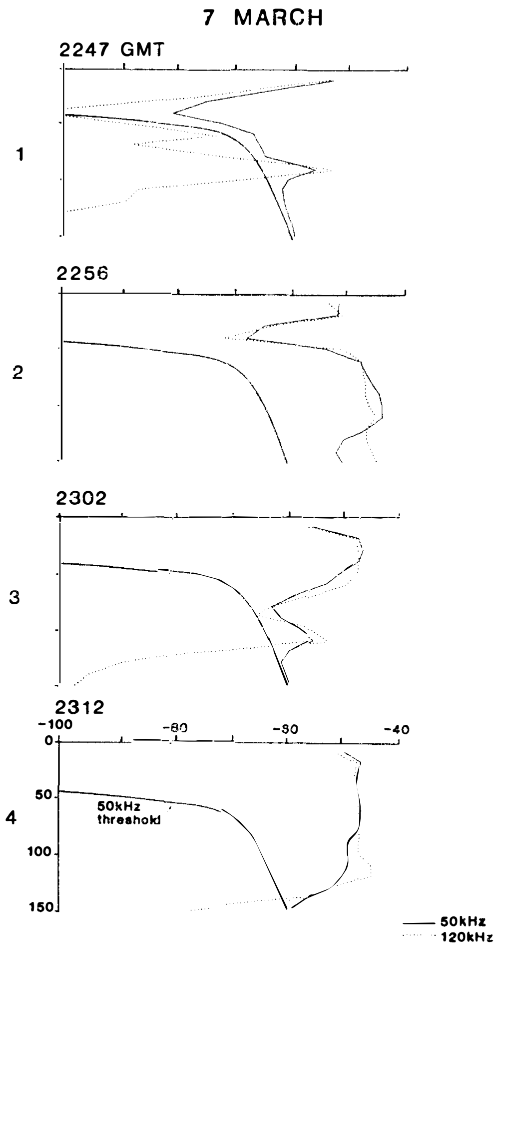


Fig. 5. Density profiles of krill, Nos. 1, _, 3, and 4, obtained March 7, 1981. The exact positions are given in Fig. 4. Depth, expressed in m on the ordinate and biomass on the abscissa measured by $\bar{S}_v$ dB for contiguous 10 m depth strata.

The corresponding denstiy profiles with depth is depicted in Fig. 5. The vertical depth scale is given in meters while the mean volume back scattering is plotted along the abscissa expressed in dB. The threshold for the 50 kHz sounder is also shown. A corresponding curve for the 120 kHz would fall to the left of the graph because of the low gain settings used with this particular instrument and its limited dynamic range of about 40 dB. Even so, observations of the tape recorded signals on the oscilloscope clearly showed that the 120 kHz sounder was saturated. The most important feature here was the uniform distribution of krill with depth in the more central parts of the swarm.

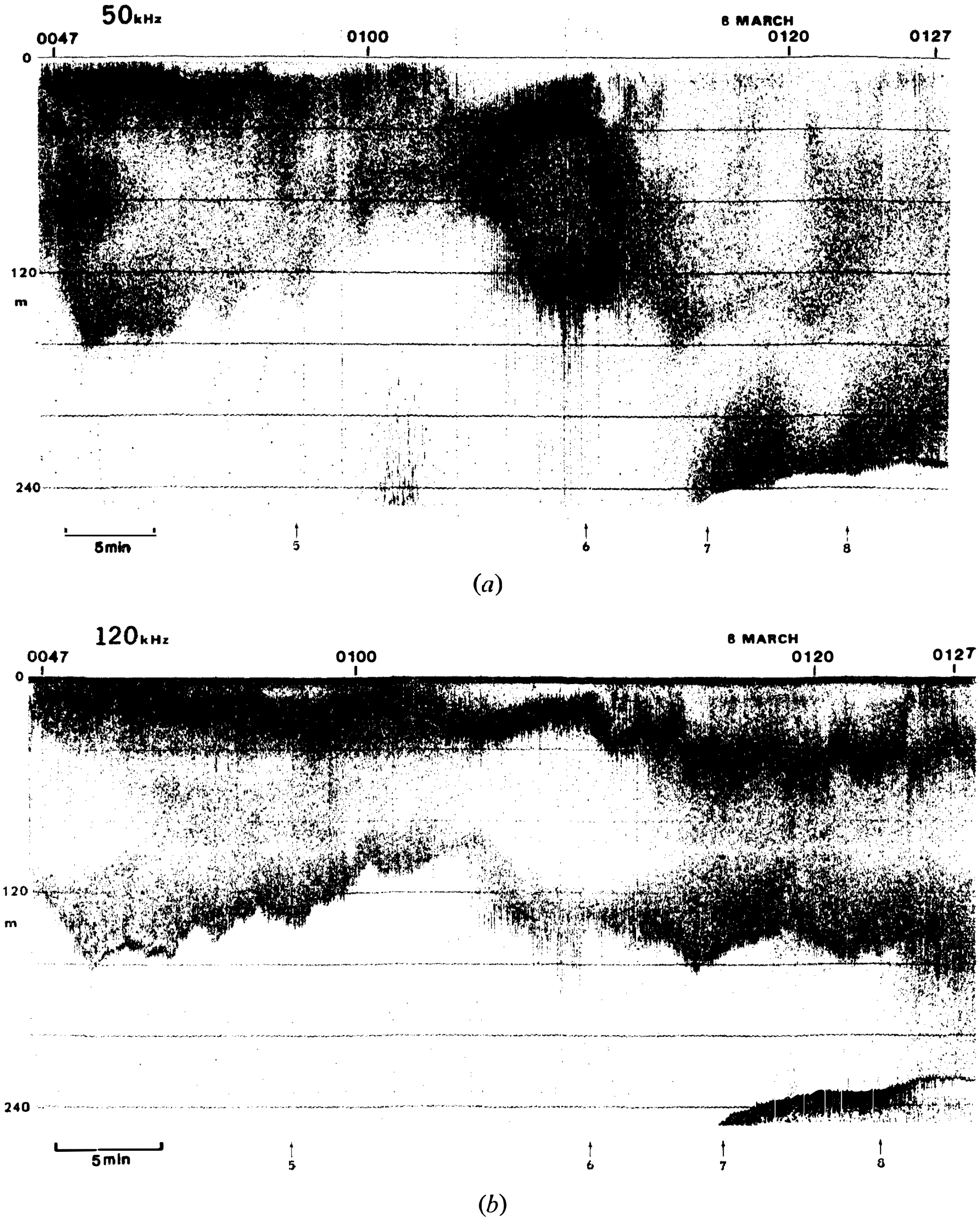


Fig. 6. Echograms recorded on March 8, 1981 from 0047 to 0127 (GMT). Position of four density profiles marked with numerals 5, 6, 7, and 8. Top echogram from a 50 kHz sounder (a). Bottom echogram from a 120 kHz sounder (b).

Another segment of the same transect obtained about 1–1/2 hours later on March 8 from 0047 to 0127 GMT, is illustrated in Fig. 6. The two echograms show the same uniform distribution with depth although the same reservations must be made for limited dynamic range of the 120 kHz sounder which went into saturation on some occasions especially in Profile 6 in Fig. 7. However at this location with a high estimated biomass, the same even distribution, from top to bottom was maintained as well as in other profiles with high biomass values. It thus appears as if the krill repel each other, possibly by their swimming activities or discharge of ammonium or other extretory products. The advantage of a uniform distribution in the water column is obvious to a filter feeding organism like krill.

At this same profile the densities were high enough and the layer extensive enough to cause some multiple scattering. More important is the heavy distribution of krill to the bottom in Profiles 7 and 8 seen in Fig. 6a obtained with a 50 kHz sounder. This same concentration is only vaguely seen in Fig. 6b obtained with a 120 kHz sounder. Because of the four times higher attenuation coefficient for a 120 kHz frequency, very little energy penetrates to the bottom here at 240 m depth. The real value of the attenuation might be even higher because of absorption in the biomass of krill, although this has not been studied to any great extent. Yudanov (1982) also discusses the increase in attenuation due to surface disturbances and which effect the lower frequencies to a greater extent than for the higher ones like 120 kHz. Normally a school of fish

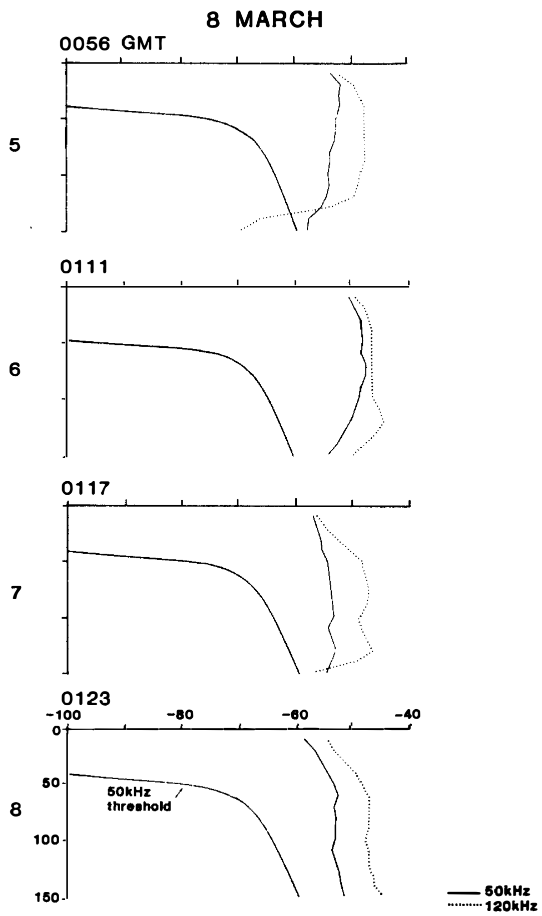
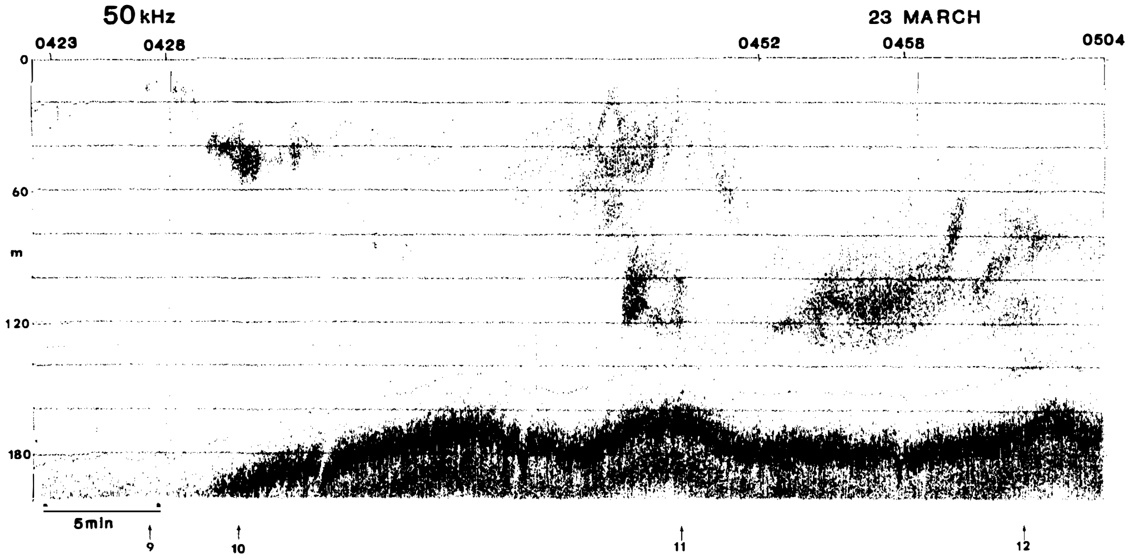


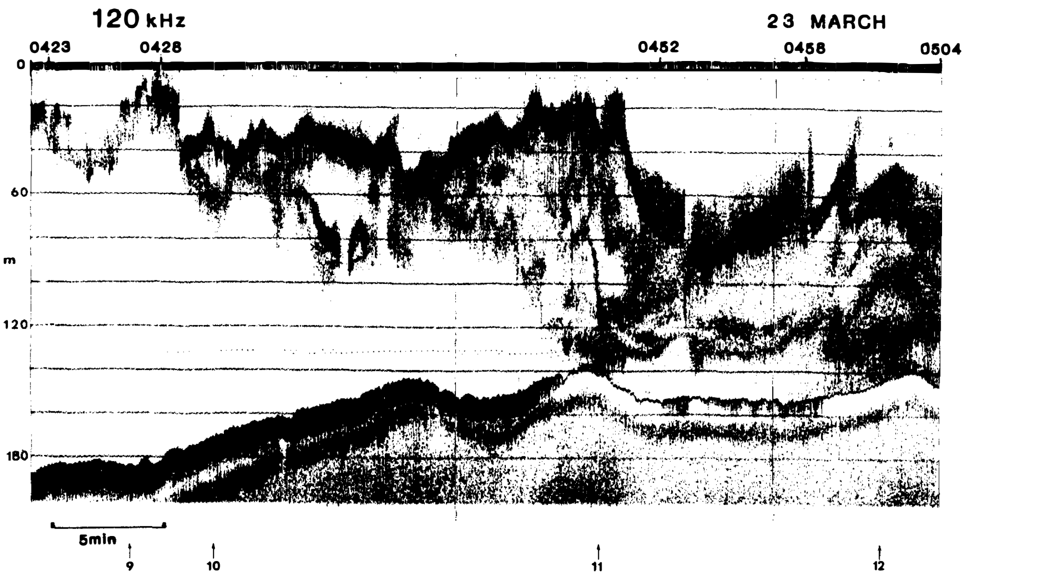
Fig. 7. *Desity profiles of krill, Nos. 5, 6, 7, and 8, obtained March 8, 1981. The exact position is indicated in Fig. 6. Depth expressed in m on the ordinate and biomass on the abscissa measured by $\bar{S}_v$ dB for 10 m contiguous depth strate on the abscissa.*

would never extend over such a wide depth range as seen in this krill school. This fact necessitates the use of multiple frequencies, not only for surveys but also for detailed studies of aggregations where densities and depth range may cause problems with high frequency sounders unless the transducer is lowered via a towed vehicle.

A final set of profiles were made on March 23, 1981. Apparently the large swarm had by this time brocken up with segments displaced in northwesterly direction along the edge of a large shelf extending from Elephant Island proper and west. Most animals were found along the edge of this shelf (BRINTON and ANTEZANA, 1982) and contained more larval forms than seen elsewhere. This is readily visible in Figs. 8a and 8b



(*a*)



(*b*)

Fig. 8. Echograms made on March 23, 1981 from 0423 to 0504 (GMT). Position of four density profiles indicated by the numerals 9, 10, 11, and 12. Top echogram from the 50 kHz sounder (a). Bottom echogram from the 120 kHz sounder (b).

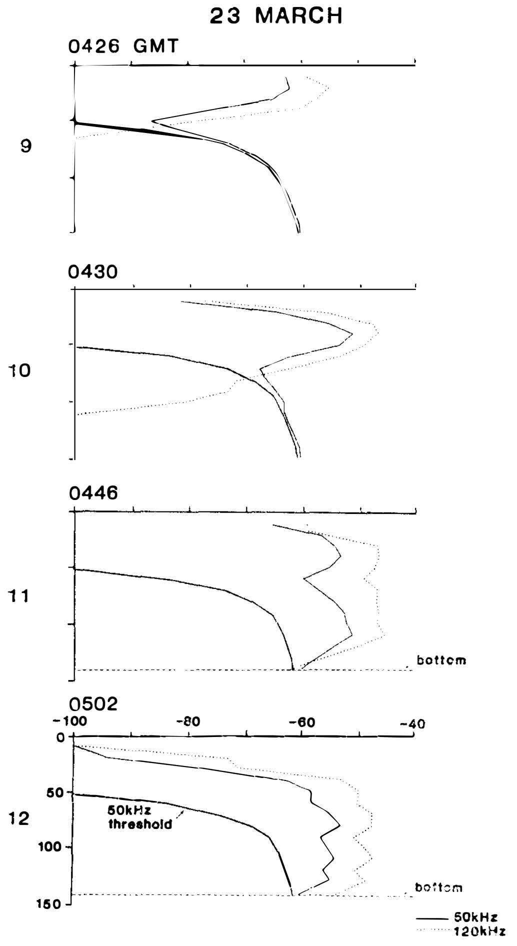


Fig. 9. Four density profiles of krill, Nos. 9, 10, 11, and 12, obtained March 23, 1981. The exact positions are given in Fig. 8. Depth expressed in m on the ordinate and biomass on the abscissa by $\bar{S}_v$ dB for 10 m contiguous depth strata on the abscissa.

which contrasts the two echograms. The immature krill (less than 2 cm) were poorly detected or not at all in the 50 kHz signal. This resulted in a lower biomass estimate from the 50 kHz sounder signals compared with the estimates obtained with the 120 kHz sounder, although the absolute differences are not too great. The primary value in this case is to establish the predominate size group without resorting to constant net hauls for placing a signature on the signals.

Because of the lower densities on this date in Profiles 9 and 10 the S_v curve follows the threshold curve created by the incorporated TVG function and serves to bring out the decrease in dynamic range with depth (Fig. 9). Otherwise the pattern is of the expected type.

4. Discussion

It has been known for more than a decade that krill possess good acoustic reflection and can be studied and assessed acoustically. However from the results of the FIBEX experiment, which involved 11 ships with a diversified array of acoustic instruments and operating on frequencies ranging from 33 kHz to 200 kHz, there emerged some special problems related to use of hydroacoustics in krill studies.

Some cannot easily be solved, such as insonification of the upper 10 m, in part because this layer is too close to the transceiver regardless of whether this is hull mounted or installed in a fin. More serious is the constant turbulence of this layer with intrusion of air bubbles. In all probability net sampling is the only consistent sampling device of this stratum.

However, by choice of proper frequencies deep aggregations can be sampled, *e.g.* in the range 100–250 m and probably even deeper. While the attenuation is well known for seawater with the temperature and salinity found in the Antarctic waters, changes may be brought about by dense concentrations of biomass especially for frequencies from 120 kHz and higher. The logical solution therefore lies in the use of multiple frequencies. In addition they allow a separation between larval forms and adults or subadults. With time the acoustic properties of other organisms like jellies, salps, and large amphipods will be studied, and multiplefr equencies may allow separation of these targets from the Euphausiids.

Multiple scattering is not only probable, but also possible in dense aggreagtions. However, because of the imperfect knowledge of the spatial distribution of krill and its transient character, it is difficult to express relationships at this time in closed mathematical form. In the super swarm studied near the Elephant Island, the densities encountered or biomass per unit volume seem insufficient for any extensive form of multiple scattering. This conclusion is also supproted by the recorded echograms. In this respect there seemed to be a difference with the krill patches studied by EVERSON (1982). He observed dense concentrations during the daytime with a dispersal of the animals at night. The Elephant Island swarm existed for several days without any great changes in internal structure. The explanation must be sought in the biological function of the various manifestations of swarming and schooling behavior.

A large biomass is concentrated in a super swarm, which demands a special treatment during surveys. Because of their rare appearances and location adjacent to geographic features like islands or ice edges they must be assessed separately apart from any regular survey. The critical parameters are both areal dimensions and depth range, but the uniformity in densities facilitates the estimation process.

Acknowledgments

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