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Effectiveness of the RMT8 System for Sampling Krill (*Euphausia superba*) Swarms

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Summary. The effectiveness of the Rectangular Midwater Trawl (RMT) for sampling krill swarms was studied by observing the behaviour of swarms in the vicinity of the net using echosounders. Large scale avoidance was observed by day but not at night. By day krill layers dispersed to such an extent that few krill were present less than 10 m below the net. Limited avoidance by night indicates that the krill are acting on visual clues of the net's presence.

Introduction

Recent increases in interest in the Antarctic Krill (*Euphausia superba*) have highlighted the need for quantitative nets with which to sample it. The first extensive research projects, such as 'Discovery Investigations', made use of traditional plankton nets (Kemp et al. 1929). These had the disadvantage, recognized at the time (Marr 1962), that the presence of bridles and a release gear in front of the mouth of the net gave large mobile organisms sufficient warning that they had time to evade the oncoming net.

Considerable progress has now been made in the development of macroplankton sampling gear and one type that has been used for krill sampling, although not specifically designed for it, is the Rectangular Midwater Trawl (RMT8) (Clarke 1969). This net has the advantages that the nominal mouth area of eight square metres is relatively large and also that the towing bridles, electronic control and release gear are not directly in front of the mouth of the net.

The present paper describes the results of part of a series of studies designed to investigate the effectiveness of the RMT8 for sampling krill and krill swarms.

Material and Methods

A multiple RMT1 + 8 system (Roe and Shale 1979) modified for use on *RRS John Biscoe* was used for all the net hauls. All net hauls were made at a constant speed of 2.5 knots with the net towed astern. At this speed the mouth of the RMT8 nets would be at an angle of 50° whilst the RMT1 nets and towing cross would be at an angle of about 69° (Roe et al. 1980).

A 120 kHz SIMRAD echosounder transducer was mounted on the towing cross at an angle of 60°. The beam of this transducer was thus pointing downwards across the mouth of the net (Fig. 1). The transducer was operated through a SIMRAD EKS 120 echosounder with its main range set to 0–100 m (referred to as Netsounder) interfaced to a SIMRAD QM analogue integrator (referred to as Net-echointegrator).

Krill were detected using a SIMRAD EK 400 echosounder with its main range set to 0–250 m operating through a 120 kHz transducer mounted amidships about half way along the hull and at 5 m depth (referred to as Hullsounder) and interfaced to a SIMRAD QD digital integrator (referred to as Hull-echointegrator). The horizontal distance between Hullsounder and Netsounder varied with the wire out but with the net at 20 m depth the Netsounder was about 60 m astern of the Hullsounder on the same track. This would give a time delay of about 1 min. All integrator data were converted to the acoustic parameter Mean Volume Backscattering Strength (MVBS) and density estimated assuming a target strength (TS) of −63.4 dB (Mean length of krill 42 mm, TS = 19.9 Logl − 95.7 BIOMASS 1985) and that there are 1620 krill per litre of catch (counts obtained from representative subsamples from all hauls in the study). The Hullsounder was used in a predetermined search pattern to determine the depth and extent of krill swarms. The echocharts were marked and the integrators reset to zero (referred to as 'resets') at intervals of 0.2 n. mi.

The net was initially set to a shallow depth of 10 to 15 m from the surface so that individual swarms or parts of swarms seen on the Hullsounder could be recognised through the Netsounder. The net was then lowered to the depth of the layer seen on the Hullsounder. Clearly for this type of operation it was advantageous to try to fish very large swarms or layers of krill.

We were fortunate in finding a large patch of krill centred on 62°19′S, 53°50′W on 16 March 1985. This patch as seen on the Hullsounder echochart was present as a group of more or less continuous layers extending from 10 to 130 m depth from the surface by day and 0 to 10 m by night. Six hauls were made on 16 March near the centre of the patch. Four of these were made on the layers nearest the surface using the Netsounder rig described above. Two of these were by day and two by night. The other hauls were made without the Netsounder. The seastate was 'slight' with a slight swell, cloud cover was 5 oktas stratocumulus. Air temperature was −2.4°C and there were many icebergs about.

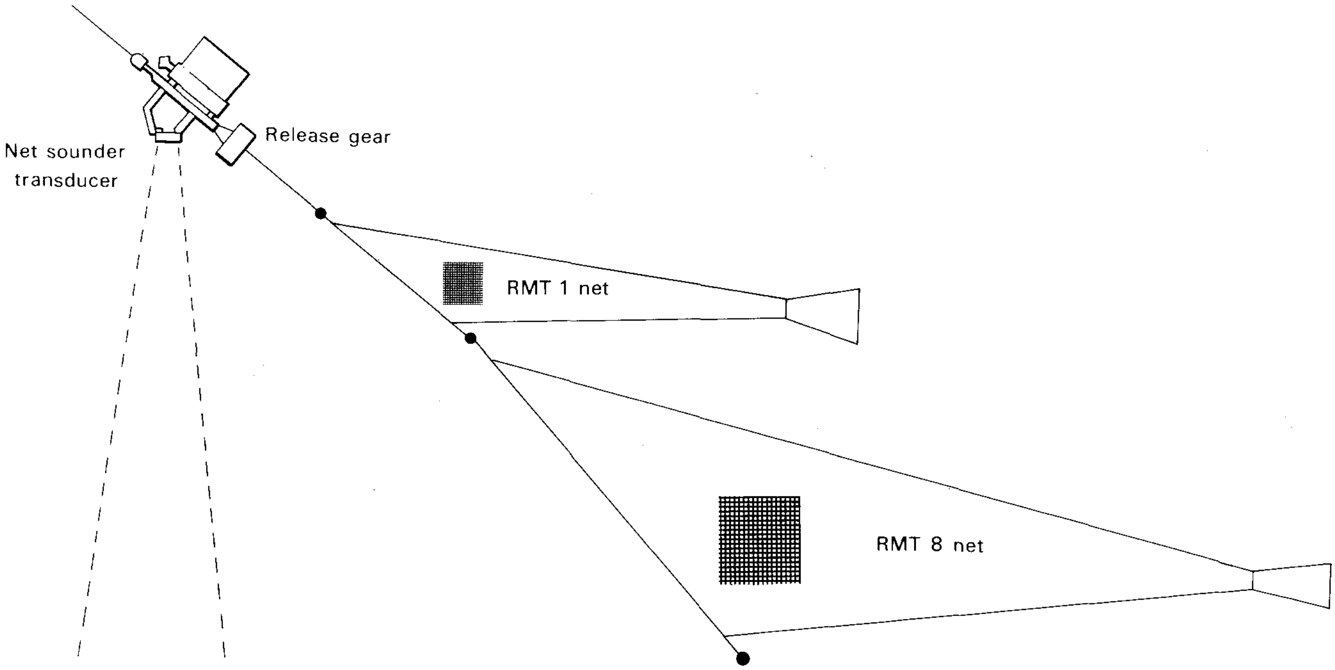

Fig. 1. Transducer configuration on RMT net rig; for clarity only a single RMT1 and RMT8 are shown

Results

Daytime Hauls

An echochart (from the Hullsounder) of part of the patch by day is shown in Fig. 2 and the estimated density of krill within each layer, based on Hull-echointegrator data is shown in Fig. 3. Two layers are distinguishable, a dense deep layer extending from 80 to 130 m which was present over part of the patch and a lower-density, near-surface layer. At one point the near surface layer became very dense (indicated by an arrow on Figs. 2 and 3 between resets 14 and 14.4).

When the net was near to the surface there was good agreement between the echocharts derived from the Hull-

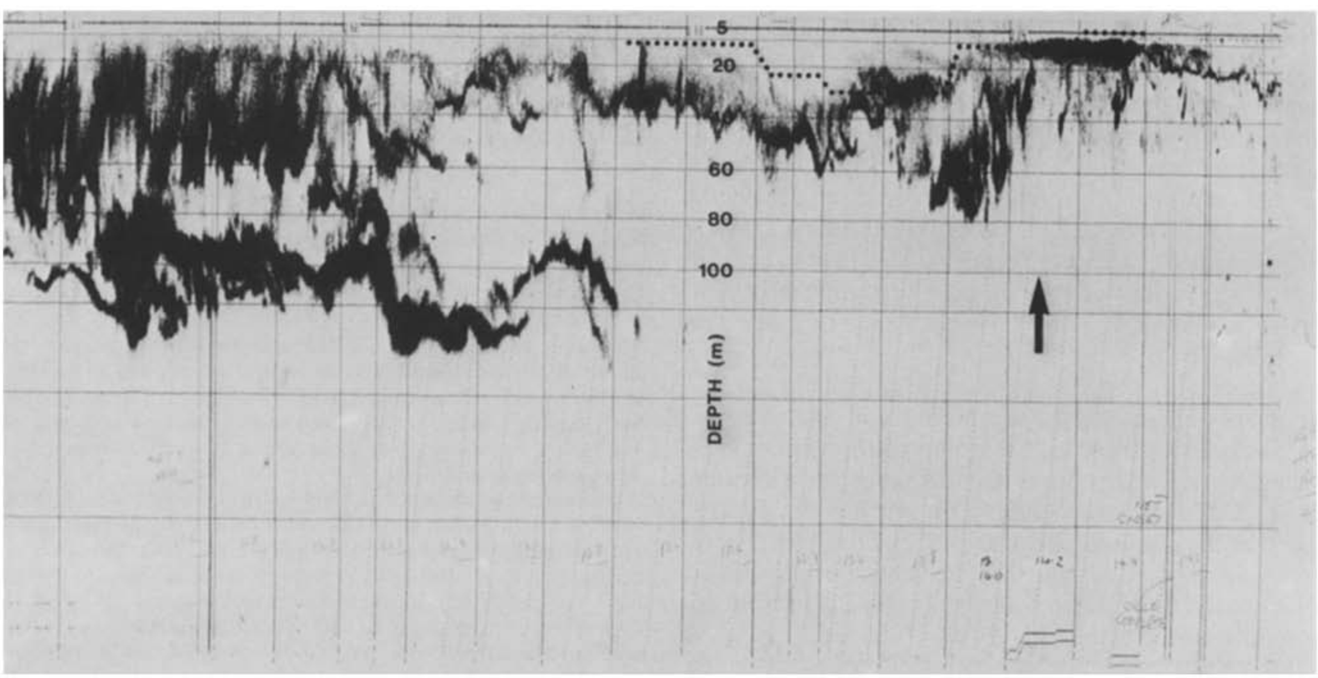

Fig. 2. Echochart of part of the large swarm prior to and during haul 1297. The *marked line* indicates the approximate net trajectory taking account of the distance of the net behind the ship. The *arrow* indicates the dense swarm indicated by an *arrow* in Fig. 3 and by *letters B* and *C* in Fig. 5

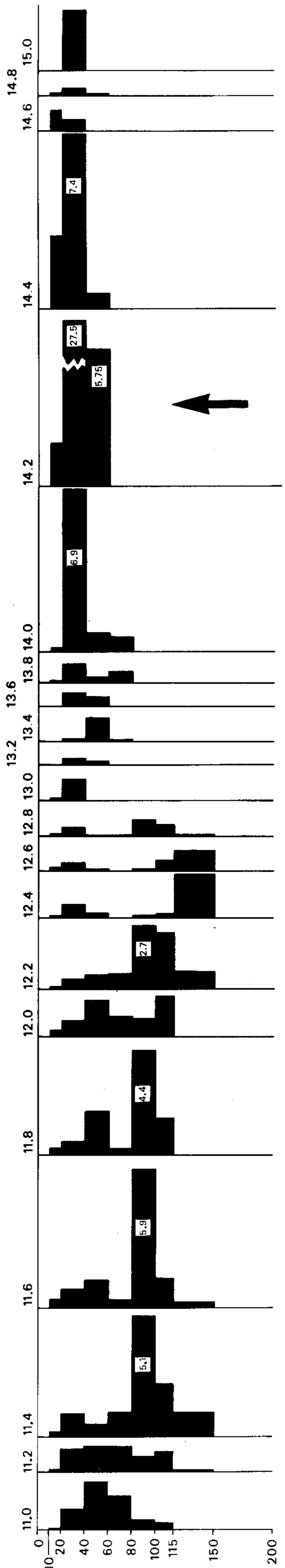

Fig. 3. Estimated krill density (no./m^3) from hull-echointegrator during haul 1297 using a standard target strength of -63.4 dB

sounder and Netsounder, but when the net was lowered towards the near surface layer the layer dispersed as the net approached. This can be seen in Fig. 4 which starts with the net at 20 m depth and the layer approximately 30 m below (i.e. at a depth of 50 m). As the net was lowered to 40 m depth it approached the layer which dispersed well before the net had reached it. With the net at 40 m depth it should have been in the krill layer although the stratum sampled by the net (indicated by an A on Fig. 4) indicated that few krill were present. As the net was raised to 20 m from the surface the layer again came visible beneath it. A similar situation is shown in Fig. 5 where when the net was less than 20 m from the surface the layer was visible 20 m below it but was not visible when the net was at 20 – 25 m or 30 m depth.

Towards the end of haul 1297, while Net 2 was still open and fishing a dense krill swarm was seen directly in its path (indicated by B and C in Fig. 5). This coincided with the very dense patch between resets 14 and 14.4 already mentioned. The catch on this occasion was 110 l (Table 1). The other daytime hauls, in spite of being fished in the krill layer seen on the Hullsounder for extended periods of time, caught relatively little. The variable depth of the net makes it difficult to compare MVBS values from the same layer as seen on the two echosounders. The only situation when such comparisons are possible is when the net was being towed continuously at a constant depth for at least two resets. Under these conditions comparisons have been made between hull and net-echointegrator values for the layer beginning at least ten metres below the net. Data from such situations during haul 1297 are summarised in Table 2. One channel of the net-echointegrator was sampling the deeper layer and this is compared with the most appropriate two

Table 1. RMT8 catch details. The duration refers to the time that the net was fished at the depth of the layer seen on the Hullsounder. All hauls were made in the depth range 20 – 40 m with the exception of 1298 which was fished at 100 m

Haul	Net no.	Time start (GMT)	Duration (min)	Catch vol (l)	Time of day	Comments
1295	1	14.34	32	7.5	day	
	2	15.06	53	6.1	day	
1297	1	16.48	39	11.0	day	
	2	17.27	30	110	day	Dense swarm at end of haul
1298	1	18.52	25	1.7	day	Net transducer removed therefore no data from Netsounder
	2	19.17	29	3.2	day	
1309	1	22.42	8[a]	27.0	night	
1311	1	00.07	2.4	9.25	night	
	2	00.12	6	8.5	night	

[a] Net in layer as seen on net sounder for 3 min but net remained open throughout the haul and probably caught a significant amount at the surface whilst being brought inboard

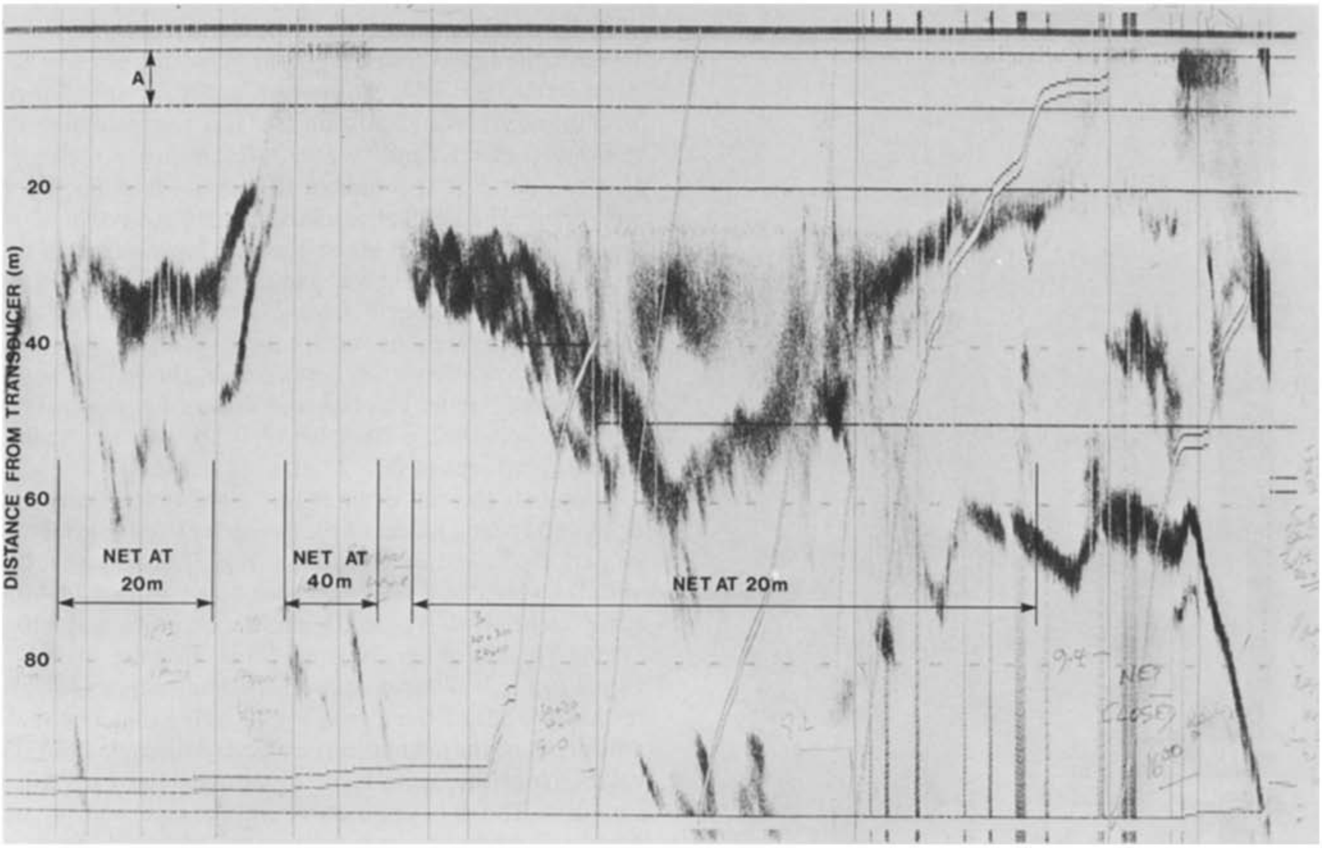

Fig. 4. Echochart from netsounder during haul 1295. A continuous layer was present at 40 m throughout the haul. The layer sampled by the net is indicated at *A*

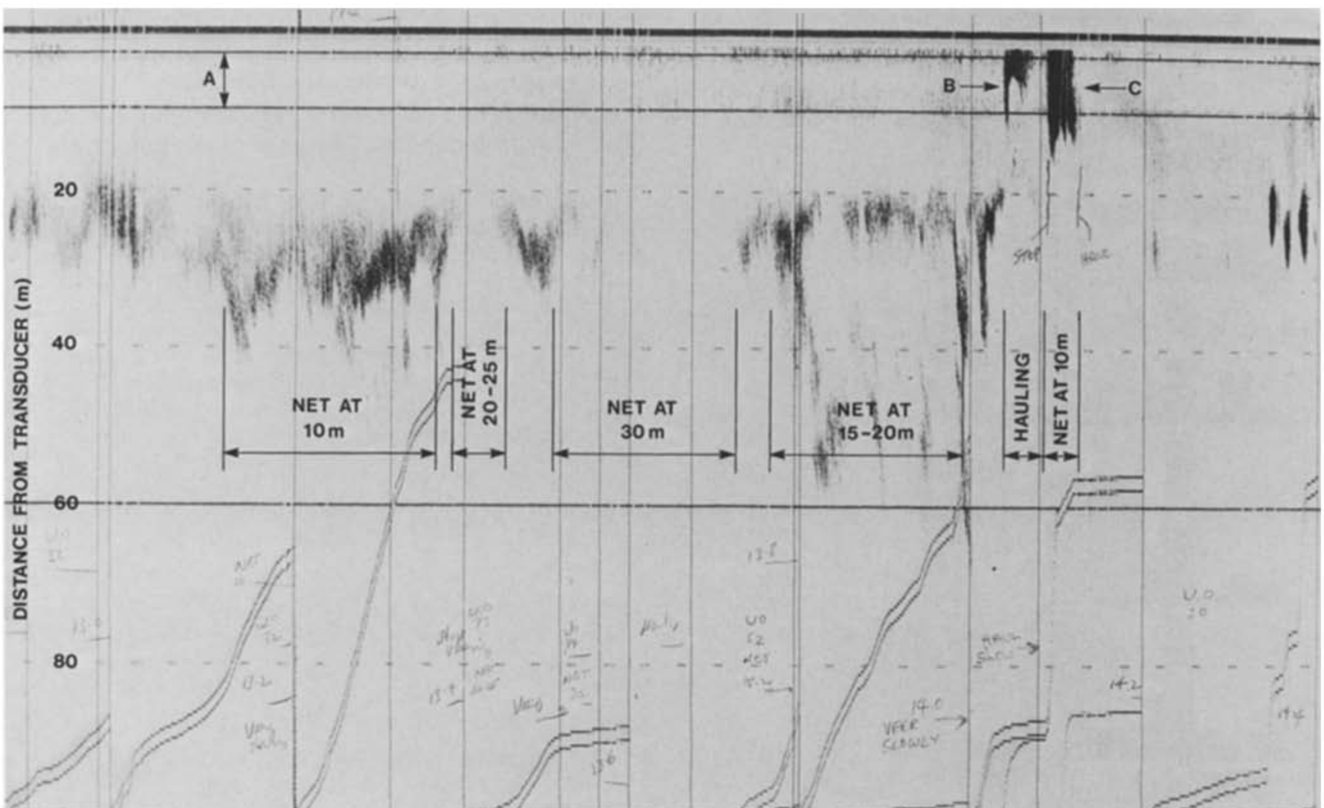

Fig. 5. Echochart from netsounder during haul 1297. The layer sampled by the net is indicated at *A*. The dense swarm referred to in the text is indicated at *B* and *C*

Table 2. Comparison of MVBS values from the two echosounders for resets during which the net was at a more or less constant depth. The hull-echointegrator values for which the layer is nearest to that sampled by the net-echointegrator are underlined

Reset	Hull echointegrator MVBS for layers			Net echo-integrator	
	20 – 40 (m)	40 – 60 (m)	60 – 80 (m)	MVBS	Approx. depth layer (m)
11.8	– 67.5	– 62.4	– 71.4	– 65.6	15 – 35
12.0	– 66.9	– 63.2	– 65.9	– 67.1	25 – 45
13.2	– 70.7	– 73.5	– 87.4	– 72.1	30 – 50
13.4	– 74.7	– 65.1	– 79.4	– 68.7	30 – 50
14.0	– 56.6	– 66.0	– 67.1	– 70.7	40 – 60

layers on the hull-echointegrator. The similarity between these two sets of data indicate that no change in krill density occurred between the layer being sampled by the Hullsounder and subsequently by the Netsounder. Differences in krill density and depth recorded on the two echosounders are therefore attributed solely to the presence of the net.

During the daylight hauls very few krill were seen within the net-echointegrator channel sampling in the path of the net. Those that did come into this layer were generally so diffuse thay they did not cause a significant deflection of the integrator (the limited dynamic range of the analogue integrator necessitated a low gain setting being selected in anticipation of high density krill swarms).

Night-Time Hauls

After dark all the krill migrated to within 10 m of the surface with the result that only small numbers were seen using the Hullsounder (Fig. 6). Two net hauls were made at this time and, on each of these when the net was lowered into the water, dense krill indications were seen through the Netsounder. No krill layers were observed either on the Netsounder or Hullsounder deeper than 10 m (Figs. 7 and 8). On hauling the net to the surface the krill layer again became visible. This process was repeated during each haul with the same result.

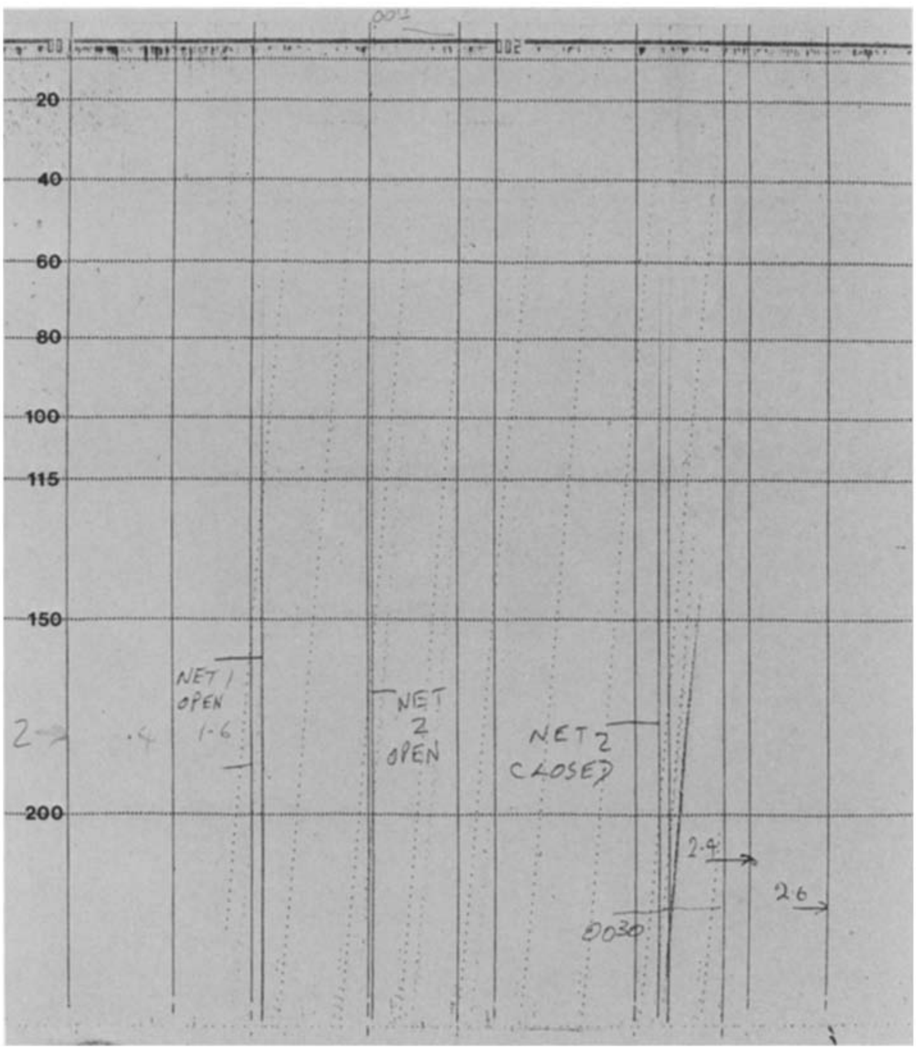

Fig. 6. Echochart from hullsounder during haul 1311

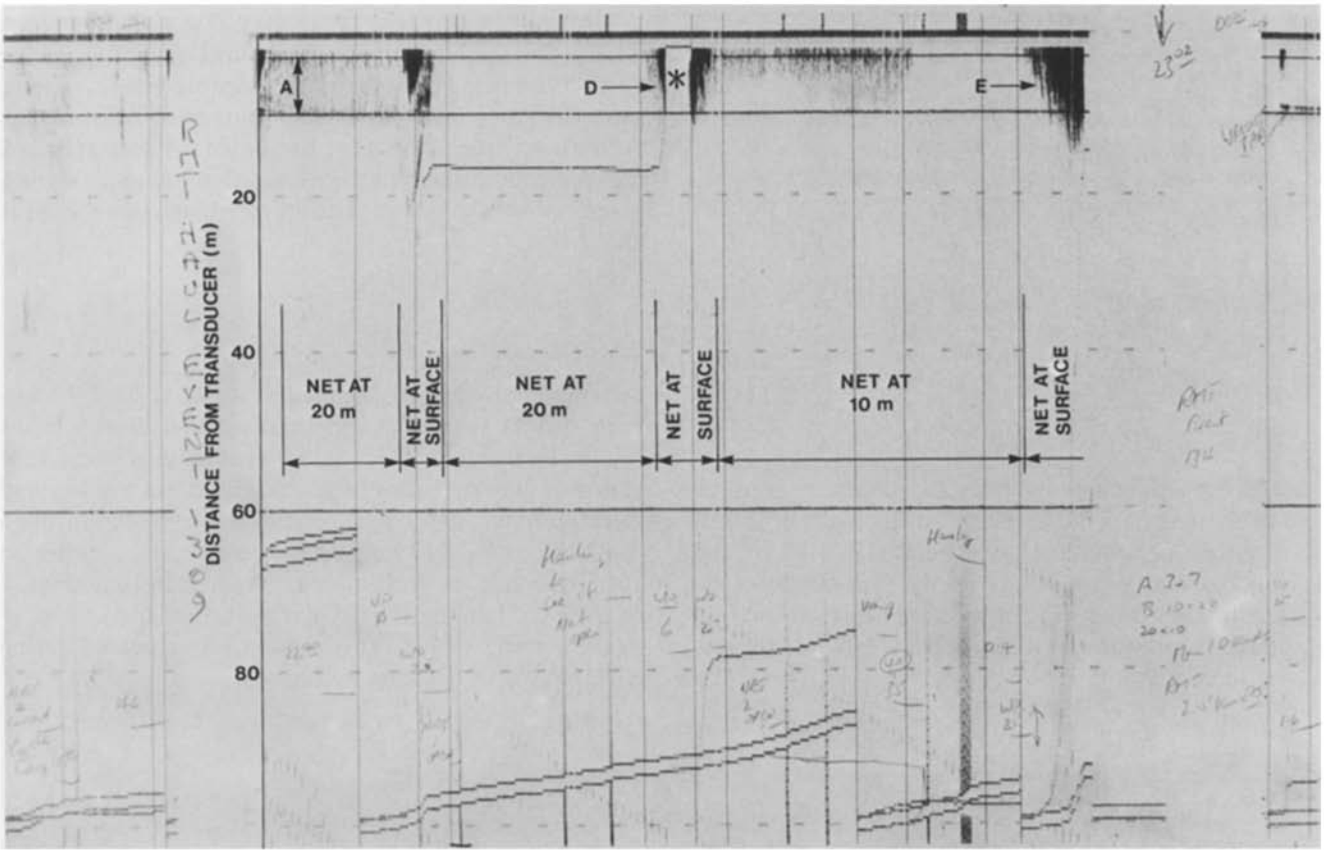

Fig. 7. Echochart from netsounder during haul 1309. The layer sampled by the net is indicated at *A*, swarms sampled are at *D* and *E*

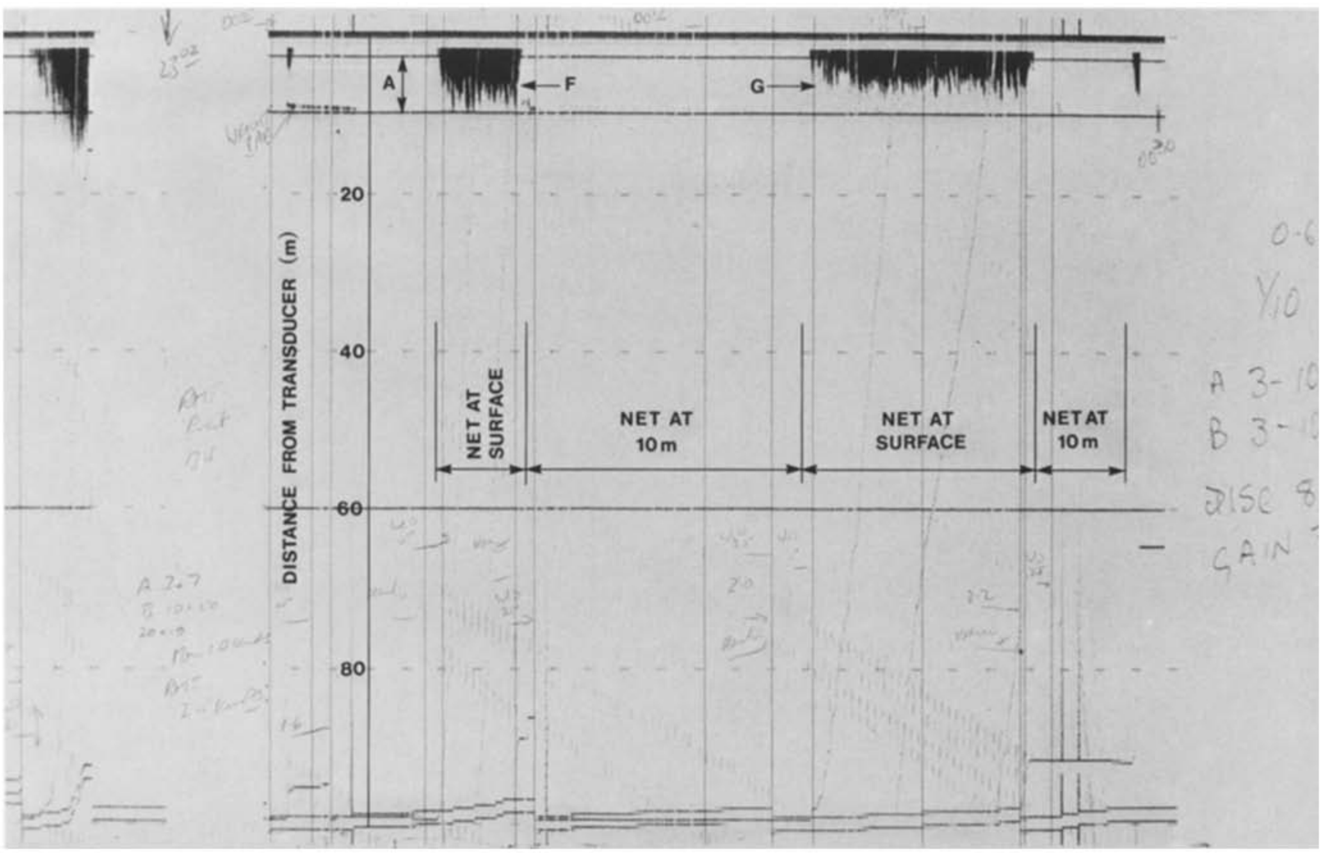

Fig. 8. Echochart from netsounder during haul 1311. The layer sampled by the net is indicated at *A*, swarms sampled are at *F* and *G*

Discussion

Comparison of the daytime echocharts from the Netsounder and Hullsounder clearly show that the amount of krill passing under the ship is much more than appears close to the net. There is, however, reasonable congruence between deeper layers seen on the Hullsounder with those seen on the Netsounder more than 10 m below the net. This difference is due either to the ship affecting the krill layer and dispersing it to such an extent that the net was fishing through clear water or the krill were becoming aware of the net and avoiding it. Based on visual observations of the reactions of a surface krill layer to the presence of a ship Marr (1962) concluded that the ship was causing the krill to move or be carried laterally thus leaving a line astern of the ship relatively clear. Catches made with a net towed on the beam were substantially higher than those with the net towed astern (Marr 1962). Furthermore, Marr's estimated density of krill caught on the beam (5200/yard^3 equivalent to 6229/m^3) is several orders of magnitude greater than that indicated by the Net-echointegrator or caught in the RMT8 in this study. The hull transducer was mounted far enough aft to assume that any effect of the presence of the ship's hull on the swarm would have taken place before the Hullsounder detected it. Differences between the depth distribution of layers seen on the Hullsounder and Netsounder are therefore assumed to be due to the presence of the net. The night-time surface catches are probably representative of what passed under the ship but these underestimate the true sample density because of the effect of ship as described above.

The net was fished shallow enough to have been clearly visible by day whilst at night bioluminescence (Boden 1969) may have made it conspicuous. In view of the higher night-time catches it would appear that the net was only clearly visible during the day.

The ship's hull has the additional complication that the propellor will stir the water up and thus disrupt swarms passing through although it is unlikely to affect the numerical density or depth range of the krill present. The night-time hauls were effectively made at the surface where the effect of propellor disturbance is likely to be greatest. In spite of this both the Netsounder und Hullsounder consistently gave indications of dense swarms. We therefore conclude that the propellor has a minimal effect at the towing speed and also that the day/night differences are due to differing reactions by the krill to the presence of the net.

In designing the present study, knowing that krill were capable of swimming at a maximum speed of about 60 cm s^{-1} (Kils 1979, 1981) we anticipated some avoidance by individual krill. Such responses would, we expected, be limited to a metre or two at the most in terms of reaction distance. The results from the present study indicate a major response at the swarm level.

The daytime hauls indicate that the swarm was affected to a depth of at least 10 m below the net. The similarity between the net and hull-echointegrator MVBS values suggests that the clear water in front of and immediately below the net does not arise from a purely downward movement of the krill; much of the krill must have gone to either side or even above the net. If we assume that all krill tended to move 10 m from the net on becoming aware of the net's presence they would need to move 10 m in 7.76 s (2.5 knots or 1.29 m s^{-1}). Such swimming speeds may be possible for short periods although they are very fast over the distance involved. A slower swimming speed would obviously be required if the detection range by the krill of the net was greater although there is no information to indicate what the actual values might be. Bearing in mind that moving sideways the krill may not have travelled so far (no facility was available to monitor sideways or upward movement) their required swimming speed would be less. The fact that large catches were made in all hauls demonstrates that not all the krill managed to evade the net. This in turn suggests that avoidance probably involves a substantially lower swimming speed than that calculated above. How much this is so is impossible to determine from these preliminary studies.

The actual catches within the layers are less than indicated by the Hullsounder. High densities as seen on the Netsounder are consistent with high catches in the net when the low light level would reduce visual clues regarding the net's presence. The high daytime catch during haul 1297 was exceptional not only for its size but also because it coincided with the densest part of the layer. This high density swarm was near to the surface. Any avoidance reaction could not have been upwards while lateral movement would have been accompanied by an increase in density. It is possible that this higher density limited the scope of the krill to avoid the net. This hypothesis would imply that large high density swarms are less able to avoid a net and also that avoidance is greatest in low and moderate density layers.

The implication of this study is clearly that using large slow-moving nets for catching krill in daytime, avoidance is likely to be a major source of error in biomass estimates. The daytime hauls, when the phenomenon was so clearly noticeable, were undertaken in favourable conditions (calm sea and good daylight) both for the operation of the gear as well as for krill to recognize and avoid the net. Further studies are clearly required to determine the sampling efficiency of the nets currently used and to give guidance in the design of sampling gear for future projects.

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References

BIOMASS (1985) Report on Post-FIBEX Acoustic Workshop, Frankfurt (FRG), September 1984

BIOMASS (in press) Rep Ser

Boden BP (1969) Observations of bioluminescence on SOND 1965 cruise of *RRS Discovery*. J Mar Biol Assoc UK 49:669 – 682

Clarke MR (1969) A new midwater trawl for sampling discrete depth horizons. J Mar Biol Assoc UK 49:945 – 960

Kemp S, Hardy AC, Mackintosh NA (1929) Discovery investigations: objects equipment and methods. Discovery Rep 1:141 – 232

Kils U (1979) Swimming performance and escape capacity of Antarctic Krill *Euphausia superba*. Meeresforschung 27:264 – 266

Kils U (1981) The swimming behaviour, swimming performance and energy balance of Antarctic Krill, *Euphausia superba*. BIOMASS Sci Ser 3, 121 pp

Marr JWS (1962) The natural history and geography of the Antarctic Krill (*Euphausia superba* Dana). Discovery Rep 32:33 – 464

Roe HSJ, Baker AC de, Carson RM, Wild R, Shale DM (1980) Behaviour of the Institute of Oceanographic Sciences Rectangular Midwater Trawls: theoretical aspects and experimental observations. Mar Biol 56:247 – 259

Roe HSJ, Shale DM (1979) A new multiple rectangular midwater trawl (RMT1 + 8 M) and some modifications to the Institute of Oceanographic Sciences RMT1 + 8. Mar Biol 50:283 – 288