SAS *Protea* Cruise, 1978; The general results of the acoustics and remote sensing study, with recommendations for estimating the abundance of krill (*Euphausia superba* Dana).

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In the late austral summer of 1977/78, a cruise was made to the western South Atlantic in SAS Protea, *with the objectives of studying krill with acoustics and remote sensing methods, making measurements of ocean colour with oceanographic and remote sensing methods, and making a small investigation of land and landwater margin features with aerial photography and spectroradiometry. Spectra of krill swarms and ocean colour were obtained. Acoustics data from krill swarms were collected from a 100 kHz side-scan sonar, a 120 kHz calibrated echo-sounder with a digital datalogger, and analogue integrator and analogue magnetic tape reader. It is concluded that remote sensing observations may be useful for some purposes, but are unlikely to be useful as a survey technique. Krill was found to be a good subject for acoustics study. Ocean colour measurements and spectra were obtained at 20 stations in the Southern Ocean, but chlorophyll values were uniformly low. Based on the results of this cruise, a number of recommendations are made to assist the development of acoustics survey methods for krill.*

Tydens die laat suidsomer van 1977/78 is 'n vaart met die SAS Protea *na die westelike Suid-Atlantiese Oseaan onderneem om kril met behulp van akoestiese middele en afstandwaarnemingsmetodes te bestudeer, die oseaankleur met oseanografiese en afstandwaarnemingsmetodes te bepaal, en met behulp van lugfotografie en spektroradiometrie 'n beperkte ondersoek na kenmerke van die land en van landseeskeidings in te stel. Akoestiese gegewens oor krilswerms is verkry met 'n kantaftastersonar (100 kHz) en 'n gekalibreerde eggopeiler (120 kHz) met 'n syferdata-aantekenaar, analoogintegreerder en analoogmagnetiese bande. Daar word tot die gevolgtrekking gekom dat afstandwaarneming vir sommige doeleindes nuttig kan wees, maar dat dit waarskynlik nie as 'n opnametegniek sal deug nie. Metings en spektra van die oseaankleur is by 20 stasies in die Suidelike Oseaan verkry, maar die chlorofilsyfers was eenvormig laag. Op grond van hierdie vaart se resultate word 'n aantal aanbevelings gedoen ter bevordering van die ontwikkeling van akoestiese opnamemetodes vir krill.*

Introduction

It has been suggested that remote sensing methods may have an application in Southern Ocean resource assessment, particularly for krill (*Euphausia superba* Dana) (El-Sayed & Green 1973), and a document was produced for the meeting of SCAR/SCOR WG 54 at Cambridge in 1975 detailing the areas of opportunity and some of the problems in remote sensing studies of krill (Cram & Malan 1978). At the meeting of the Group of Experts on the Living Resources of the Southern Ocean at Woods Hole in August 1976, the discussion of remote sensing was carried further and some potentially useful programmes included in the objectives of the research programme named BIOMASS (Anon 1977).

During the working sessions at the Woods Hole meeting, the value of acoustic investigations on krill were emphasised and a suggestion was made that the Sea Fisheries Branch of the Department of Industries (Republic of South Africa) would endeavour to arrange a cruise with a vessel suitable for both remote sensing and acoustics studies. The result was a cruise from 10 February to 21 April 1978 aboard SAS *Protea*, an ice-strengthened, helicopter-carrying hydrographic research vessel.

The objectives of the cruise were to conduct remote sensing and acoustics studies into certain elements of the Southern Ocean ecosystem. Ocean colour (phytoplankton), krill swarms, kelp and penguins were studied by remote sensing, whilst krill swarms were investigated with a variety of shipborne acoustics gear as well as with an echo-sounder installed in a helicopter.

The United States National Aeronautical and Space Administration accepted a proposal made on behalf of the Group of Experts by their Convenor, that LANDSAT 2 data be collected over certain sub-Antarctic islands during the cruise of the *Protea*.

Cruise Strategy

No attempt was made to plan an orthodox survey. The cruise plan called for the vessel to remain in a suitable area until the scientific work was completed, rather than to adhere to a rigid schedule (Fig. 1). Helicopter flights for ocean colour studies were attempted every day throughout the cruise, whilst remote sensing studies of krill were only attempted when krill had been detected acoustically.

Shipborne acoustics research was conducted primarily during the daytime from before dawn until after dusk. Acoustics studies were not made at night in the krill "zone" as the ship was either stationary or moving too slowly to accomplish meaningful work. The overall strategy was to pick a restricted set of objectives and to adhere to them, so concentrating the limited manpower in order to achieve greater impact than would have been possible with more numerous objectives.

Remote sensing studies on krill

Fish populations with a patchy distribution are difficult to survey: a trade-off exists between intensification of the grid (to increase the number of encounters with shoals so reducing the variance in any measurements) and the widening of the grid to ensure that the geographical range of the population is covered (Cram & Hampton 1976). An aerial/acoustic strategy had been developed for the Southeast Atlantic pilchard population (*Sardinops ocellata* Pappe), where aerial observa-

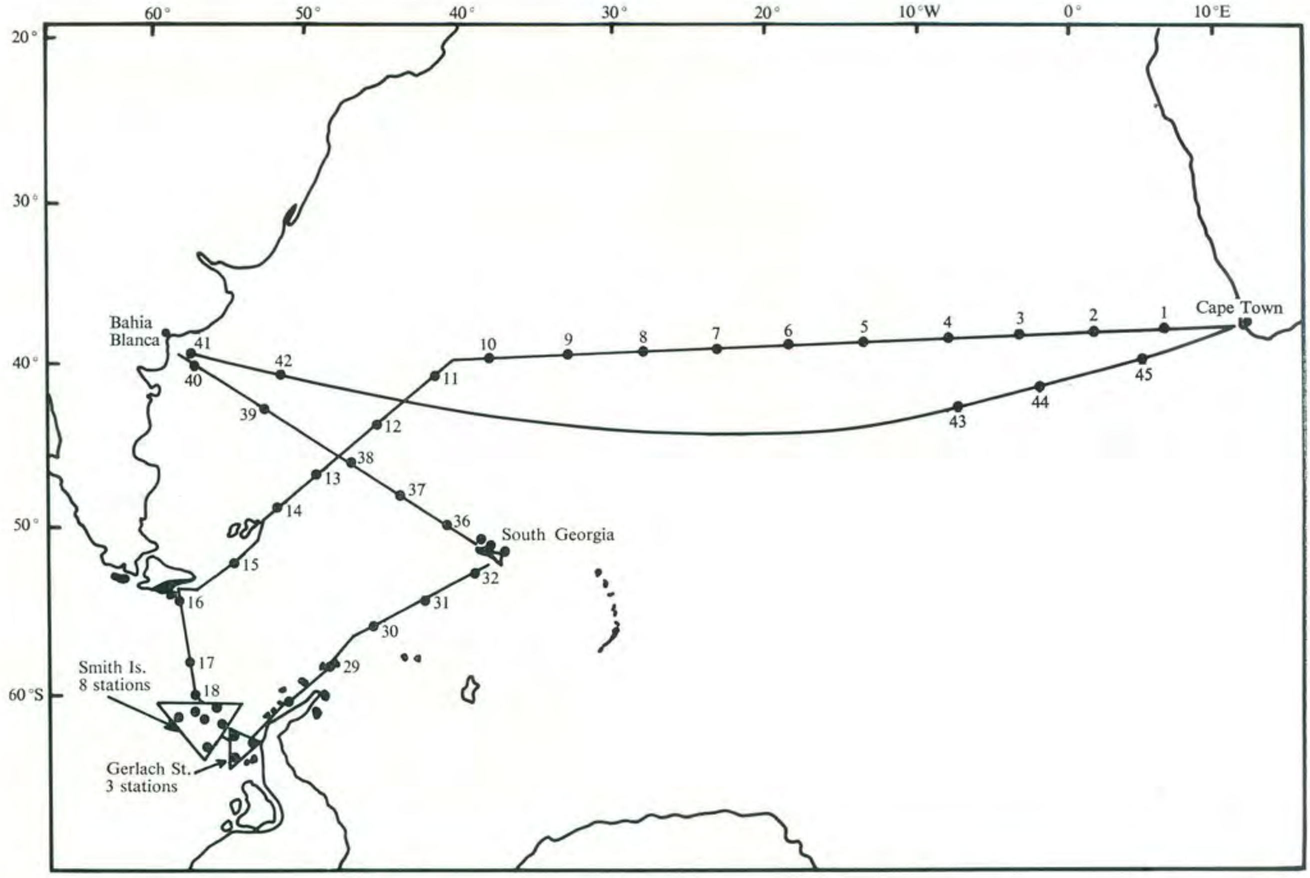


Fig. 1. Cruise track showing noon station positions and station numbers.

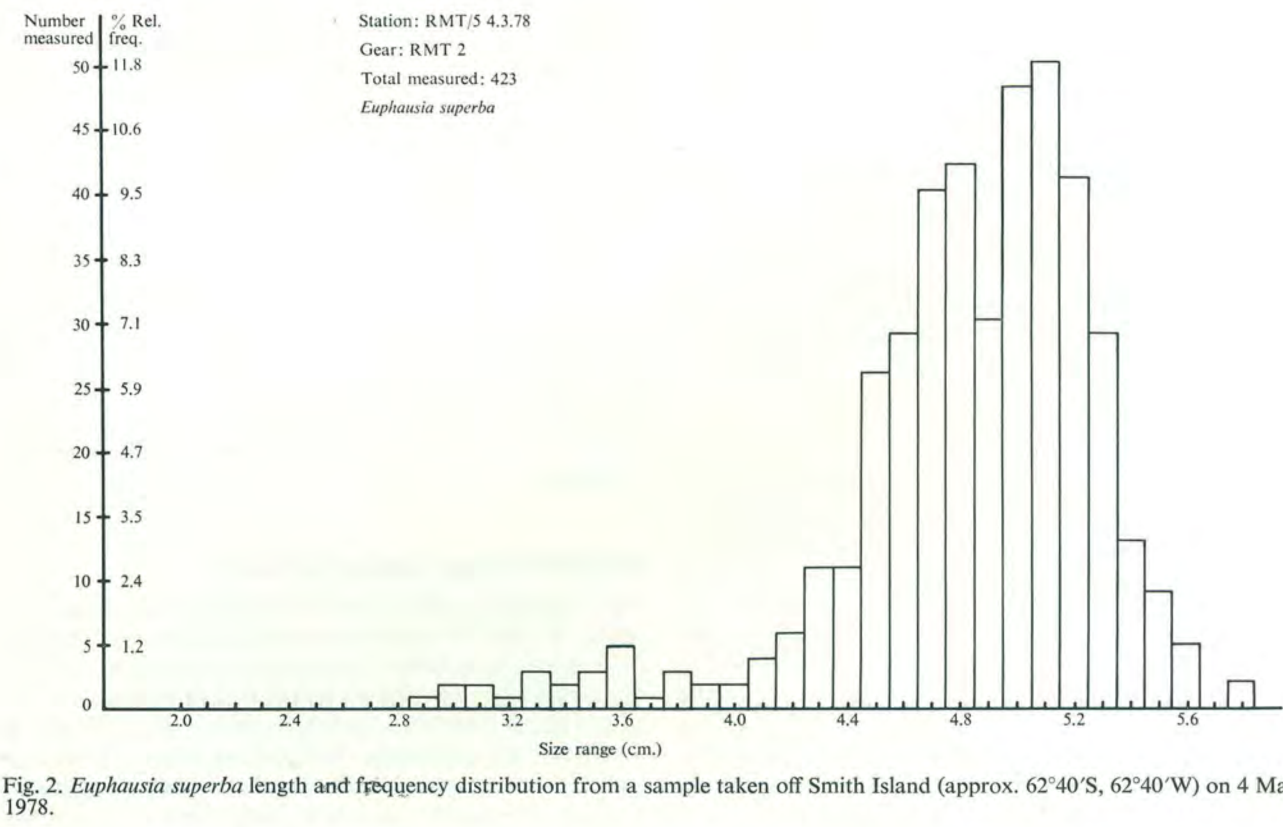


Fig. 2. *Euphausia superba* length and frequency distribution from a sample taken off Smith Island (approx. 62°40′S, 62°40′W) on 4 March 1978.

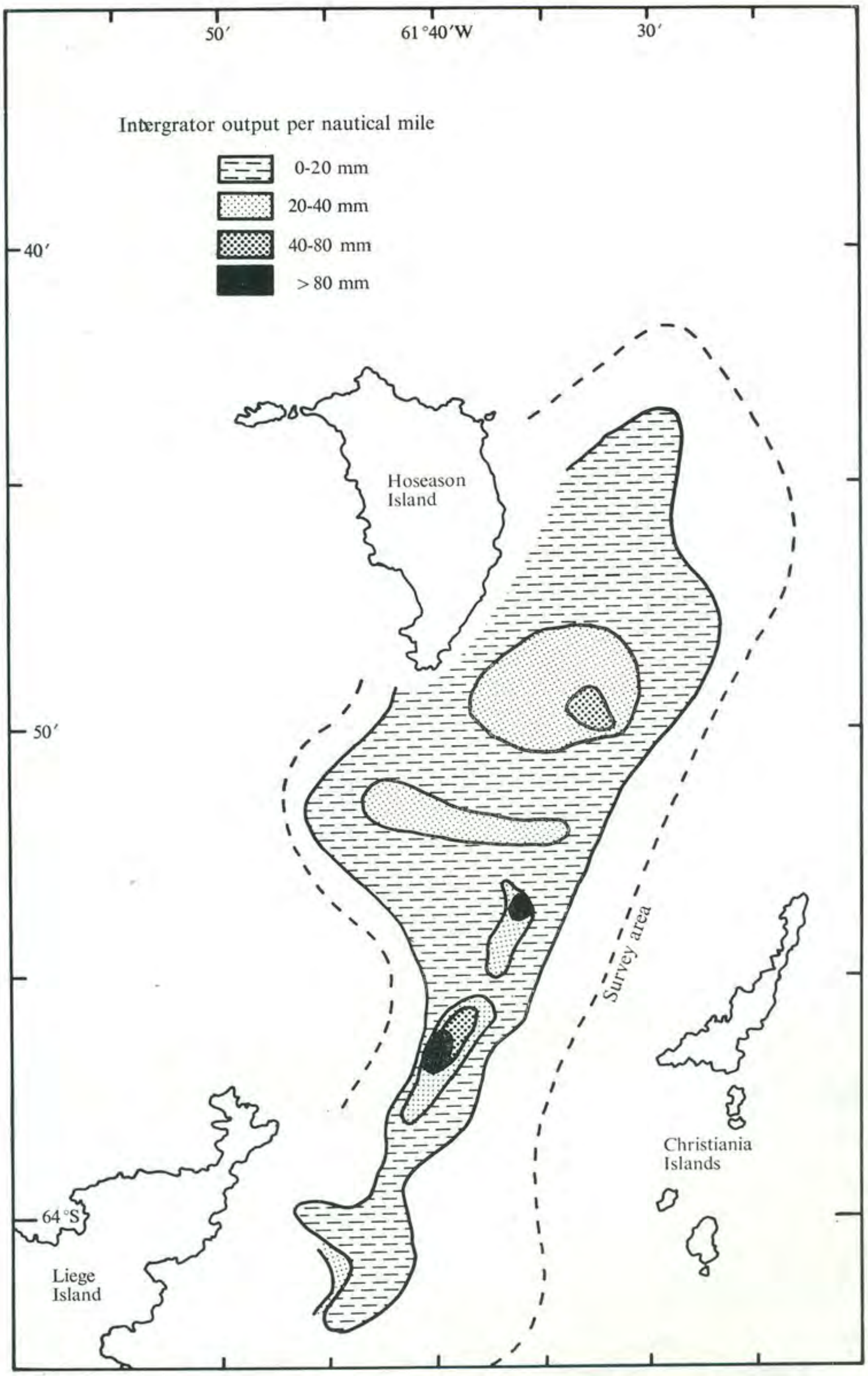


Fig. 3. Density structure of a krill swarm group in the Gerlache Strait (approx. 64°30′S, 62°00′W). The contour intervals are expressed in millimetres of integrator output per nautical mile

tions were used to estimate shoal group horizontal dimensions and to concentrate shipborne acoustics measurements of fish density within shoals into areas of higher fish abundance. It has been estimated that a precision of about 50 per cent is achievable with this method (Hampton *et al.* 1978).

The literature suggested that krill may have a similar patchy distribution within a vast range, also that a remote sensing study might have distinct advantages (Marr 1962, Mackintosh 1972, El-Sayed & Green 1973, Cram 1978, Cram & Malan 1978). An investigation into the feasibility of an aerial/acoustic study therefore seemed justified. Experiments were conducted from the SAS *Protea* to determine firstly, whether observations of krill from low altitudes were possible, and secondly, whether detection by satellite would be feasible.

Methods

The technique used was to launch the helicopter for a visual search during the morning and afternoon when the vessel was in the vicinity of krill swarms which had been detected acoustically. The helicopter carried a 0.25m Ebert spectroradiometer and fast graph paper recorder for the collection of spectral data from the sea. A considerable number of attempts were made to collect spectra from krill but, despite the ability to hover, it was not always easy to maintain visual contact with swarms to ensure their inclusion in the field-of-view of the spectroradiometer. Whenever possible, swarms which were located visually were insonified with a helicopter-borne 50 kHz echo-sounder in order to determine their depth.

Results

A large group of swarms mostly 30-50 m deep was located acoustically just north of Smith Island (South Shetland Islands, 62°40′ S, 62°40′ W), but despite seven flights of about 30 minutes each over the area, only very few were located visually. The swarm group was undetected despite good water clarity (Secchi disc extinction depth averaged 15 m), good viewing conditions and the fact that the krill were strongly coloured and large (modal 51 mm, see Fig. 2). One yellow-brown coloured swarm of about 5 by 3 m was insonified with the helicopter-borne echo-sounder, and proved to be less that 2 m deep (Fig. 4e).

Large swarms encountered in the Gerlache Strait (64°30′ S, 62°00′ W) were also undetected from the air although 13 flights were made in the area. The inability to detect these krill from the air was convincingly demonstrated when the *Protea* was making acoustic measurements on a particularly large swarm (Fig. 4c). The helicopter-borne echo-sounder was used close to the ship, displaying two krill aggregations, one at 4 m, the other at 20 m below the surface (Fig. 4e). The aggregation at 4 m was invisible to the observers in the helicopter, two of whom were experienced in locating fish from aircraft. The ship's scientific echo-sounder was marked whilst the echo-sounding from the helicopter was in progress, and it was clear that the helicopter echo-sounding had occurred on a super-swarm with a horizontal dimension of about 1 000 m and a depth mostly shallower than 5 m, the depth of the ship's transducer (Fig. 4c). This super-swarm remained undetected despite extensive searches by the observers in the helicopter under the ideal viewing conditions, at altitudes from sea level to 1 600 m. Krill samples taken in this area had a modal length of 39 mm (Fig. 5) and were poorly coloured.

Although the large swarms accessible to the ship were invisible from the air, other very small swarms were visible in shallow water near the islands in the entrance to the Gerlache Strait. These swarms were extremely "thin", having the appearance of lace, and were coloured yellow, orange, pink and reddish-brown. As photography was unsuccessful, no measurements of size could be made, but it is doubtful if any

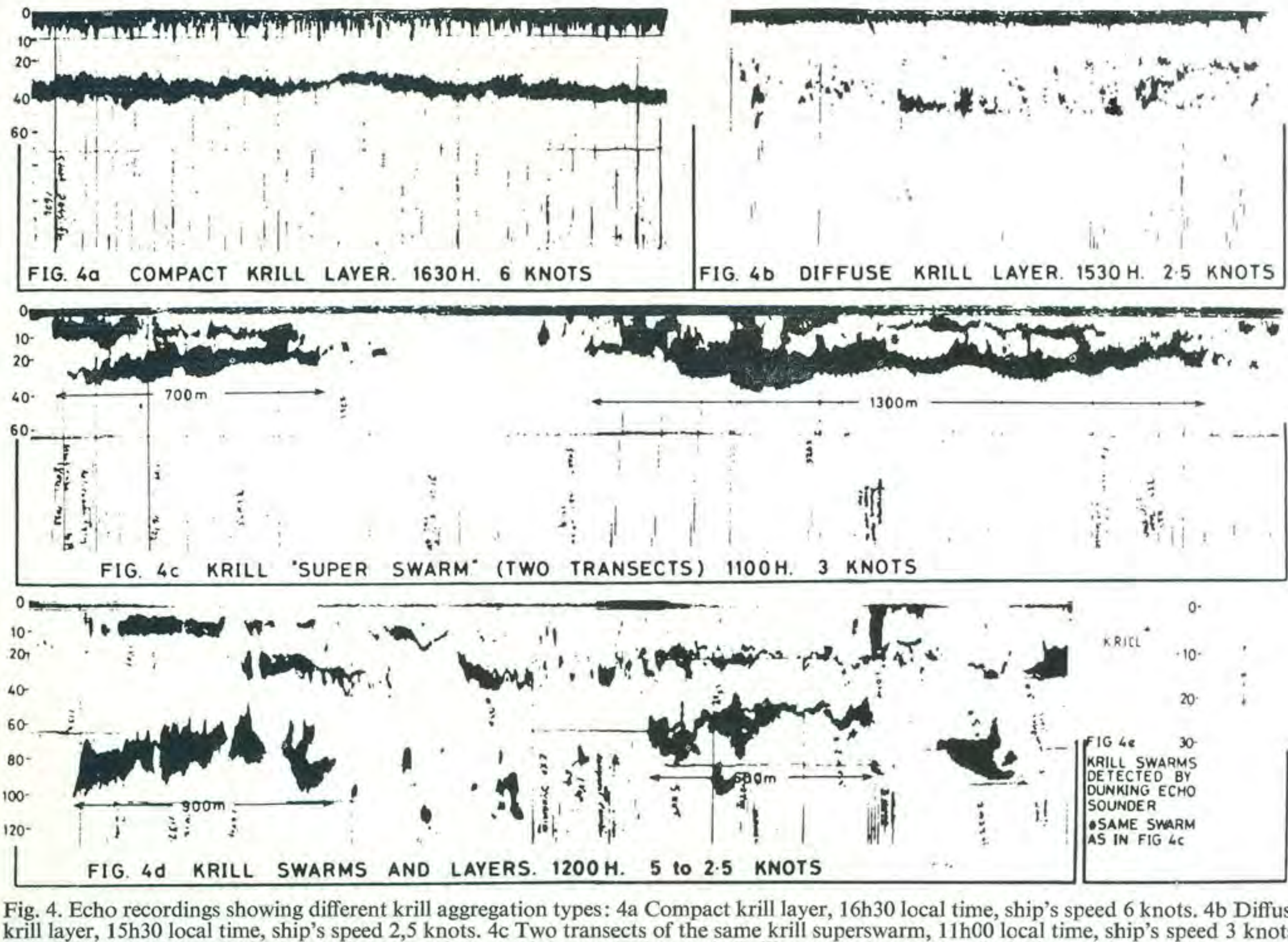


Fig. 4. Echo recordings showing different krill aggregation types: 4a Compact krill layer, 16h30 local time, ship's speed 6 knots. 4b Diffuse krill layer, 15h30 local time, ship's speed 2,5 knots. 4c Two transects of the same krill superswarm, 11h00 local time, ship's speed 3 knots. 4d Krill aggregations of mixed type, 12h00 local time, ship's speed 3 knots. 4e Krill swarms detected by the helicopter-borne echo-sounder. On the left, marked 'krill' is a swarm at less than 2 m depth and on the right is the echogram taken whilst the ship's echo-sounder recorded the super-swarm in Fig. 4c. The corresponding part of the echogram in Fig. 4c is marked by a barely distinguishable asterisk above the legend "1300 m" between the upper and lower parts.

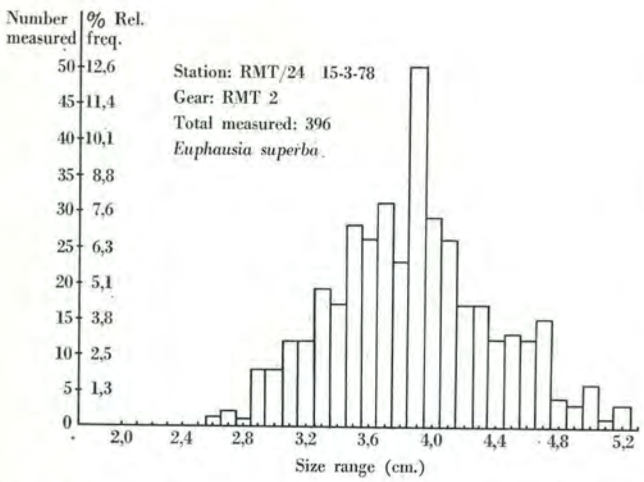


Fig. 5. *Euphausia superba* length and frequency distribution from a sample taken in the Gerlache Strait (approx. 64°30′S, 62°00′W) on 15 March 1978.

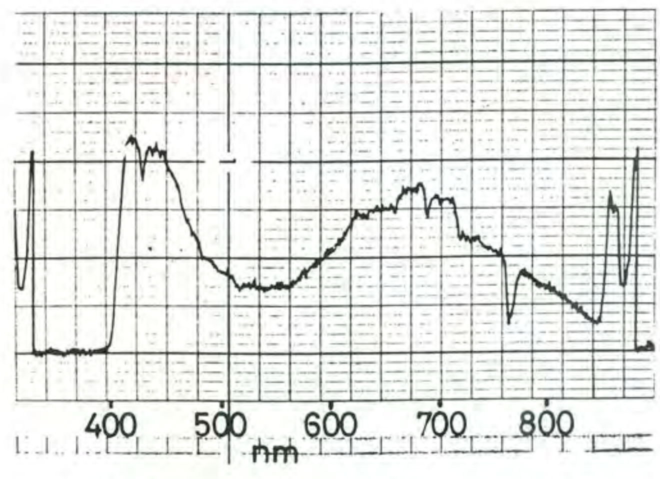
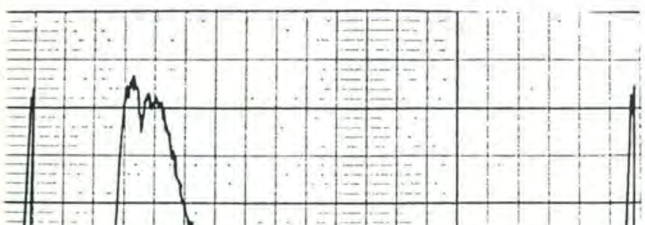


Fig. 7. Spectrum taken on deck from a sample of krill.



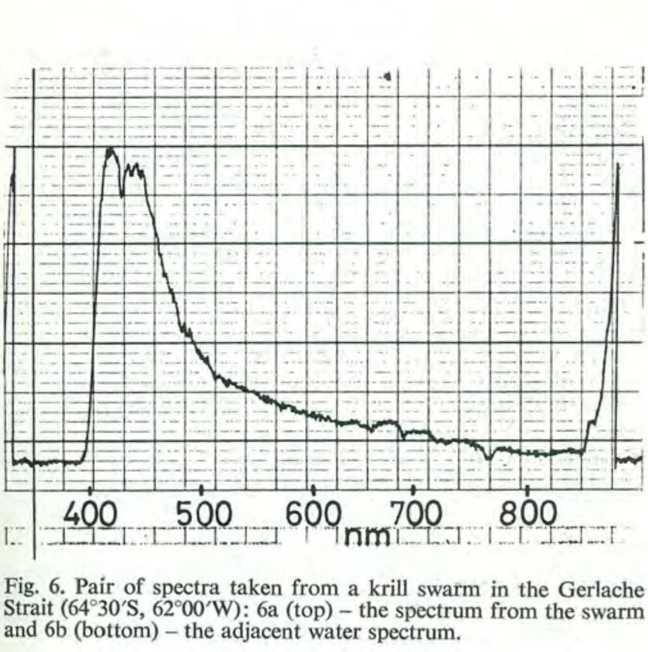


Fig. 6. Pair of spectra taken from a krill swarm in the Gerlache Strait (64°30′S, 62°00′W): 6a (top) – the spectrum from the swarm and 6b (bottom) – the adjacent water spectrum.

swarm was larger than 30 m at its longest axis, and most were considerably smaller. Spectroradiometric measurements were accomplished on these swarms, but mostly under very poor light conditions.

Twelve pairs of spectra have been examined for this report, representing five encounters with swarms on two days (11 March and 16 March 1978). Each pair of spectra consists of the krill-bearing water spectrum and an adjacent clear water spectrum (Fig. 6). It is difficult to distinguish one from the other by eye. The spectra recorded on the fast paper recorder were manually digitised at 1 mm intervals, approximately corresponding to the spectral resolution of the spectroradiometer (4 nm). The spectra were normalised, with the value at each point between 400 and 800 nanometers expressed as a fraction of the total within the region.

As krill in bulk are red (confirmed from the spectra taken of samples on deck, Fig. 7), a depression in the blue and an increase in the yellow-red parts of the spectra were expected. Subtracting the normalised "water" spectrum from the normalised "krill" spectrum, about half the spectra showed the expected depression at 400-500 nanometers (violet-blue) and an increase over a wide, not clearly defined, zone at approximately 525-675 nanometers (green to near-infrared) (Fig. 8).

The depression measured at 420 nanometers on the krill spectrum in Fig. 6a amounted to 8 per cent of the normalised value for the same wavelength in the corresponding sea spectrum in Fig. 6b. The increase measured at 620 nanometers in the same normalised spectrum amounted to 22 per cent.

Hydroacoustics

Although krill are known to be good sound scatterers, the numerous questions raised in the BIOMASS Research Proposals (Anon 1977) indicated that more research is necessary before it is known whether or not the krill population can be successfully surveyed acoustically. Consequently, an attempt was made to collect acoustic data on the structure of krill aggregations as well as on their behaviour.

Methods

The principal equipment used was a 120 kHz calibrated echosounder with hull-mounted and towed transducers. The receiver output was digitised and stored in a mini computer-

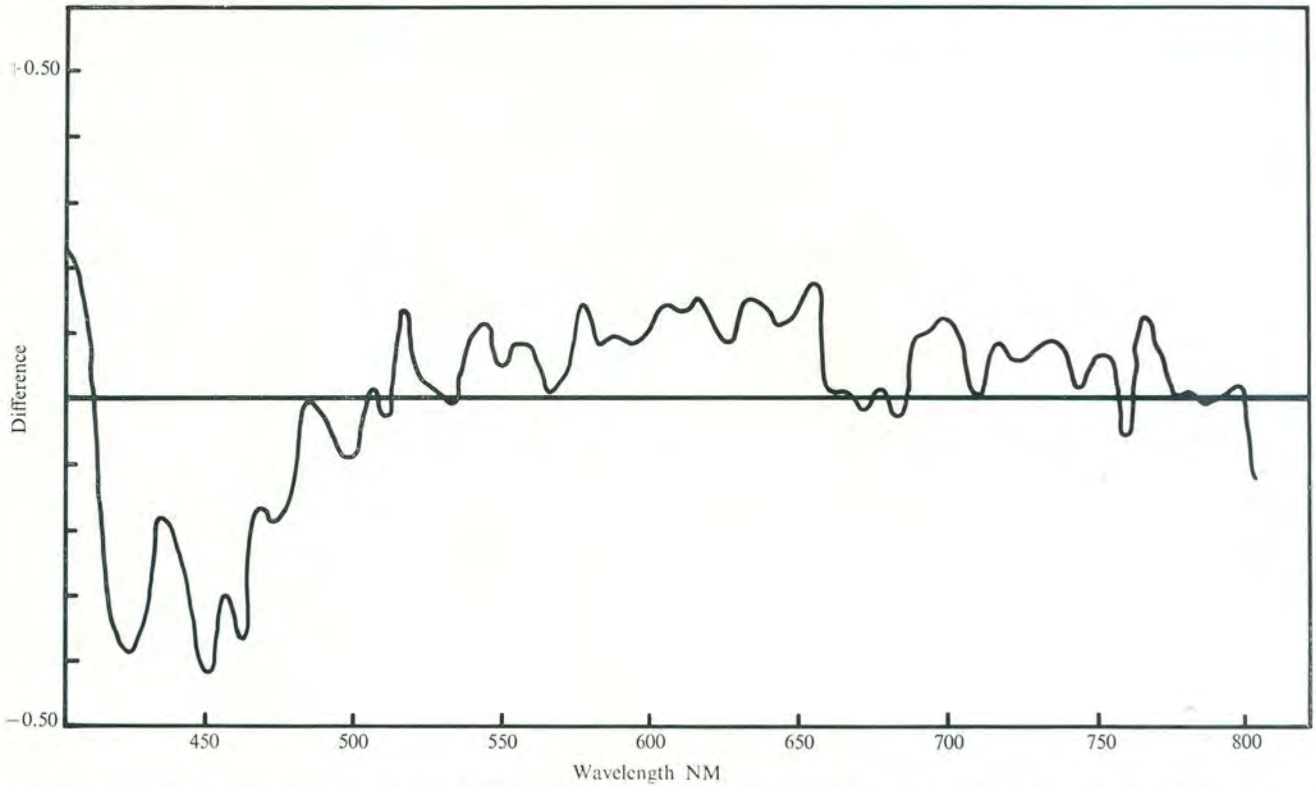


Fig. 8. Difference between the normalised krill and water spectra, showing the depression in the violet-blue, and the increase in the green to near-infrared parts of the spectrum.

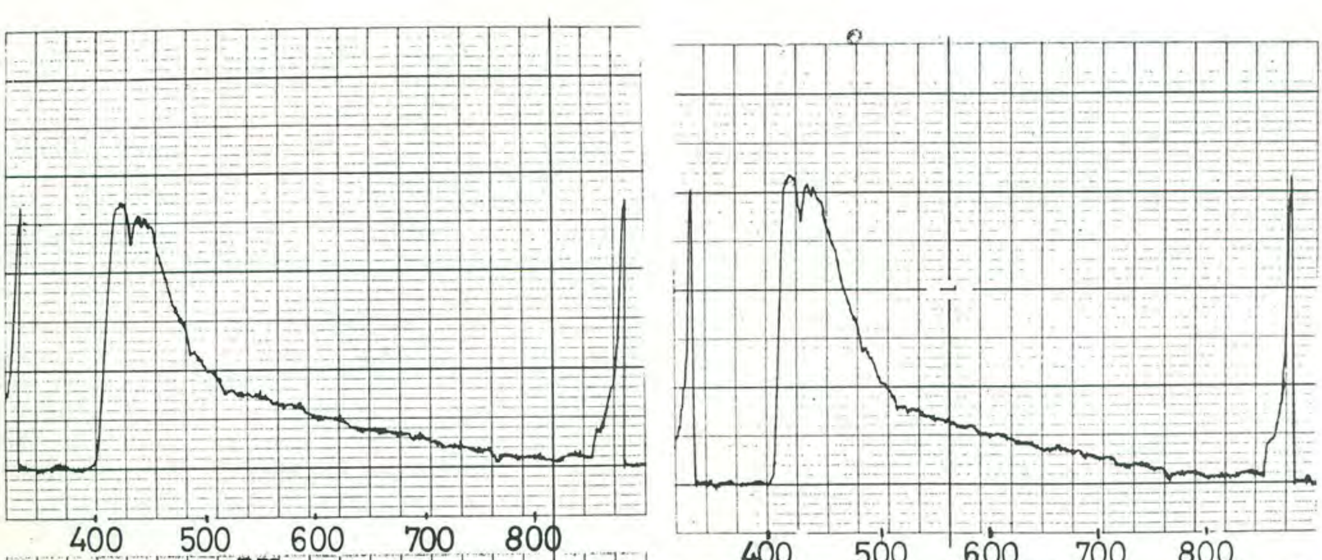


Fig. 9. Ocean colour spectra: 9a (left) – spectrum of maximum chlorophyll a, 2,4 mgm/cubic metre at the surface and 9b (right) – spectrum of minimum chlorophyll a, 0,0 mgm/cubic metre at the surface, 0,5 mgm/cubic metre at 60 m.

based digital data logger (Hampton & Glaum 1975), processed by an analogue integrator and also displayed on a wet-paper recorder. A multichannel FM tape recorder was available as back-up in case of recorder malfunction. In addition a towed 100 kHz side-scan sonar was used to evaluate the role of high frequency sonar.

The identity of sound scatterers was established with a modified RMT-8 net (Robertson 1979) to which was attached a 120 kHz towed transducer as a net monitor (Fig. 12).

Results

Two concentrations of krill were extensively studied, one off Smith Island and the other in the Gerlache Strait. In general, three different types of krill aggregations were detected: "layers", "swarms" and "super-swarms". The term "layer" is used to describe aggregations which extend continuously over large distances, often many kilometres. They can be either vertically thin (Fig. 4a), vertically thick, or diffuse (Fig. 4b). Those layers observed varied very considerably in depth below the surface. The term "swarm" is used to des-

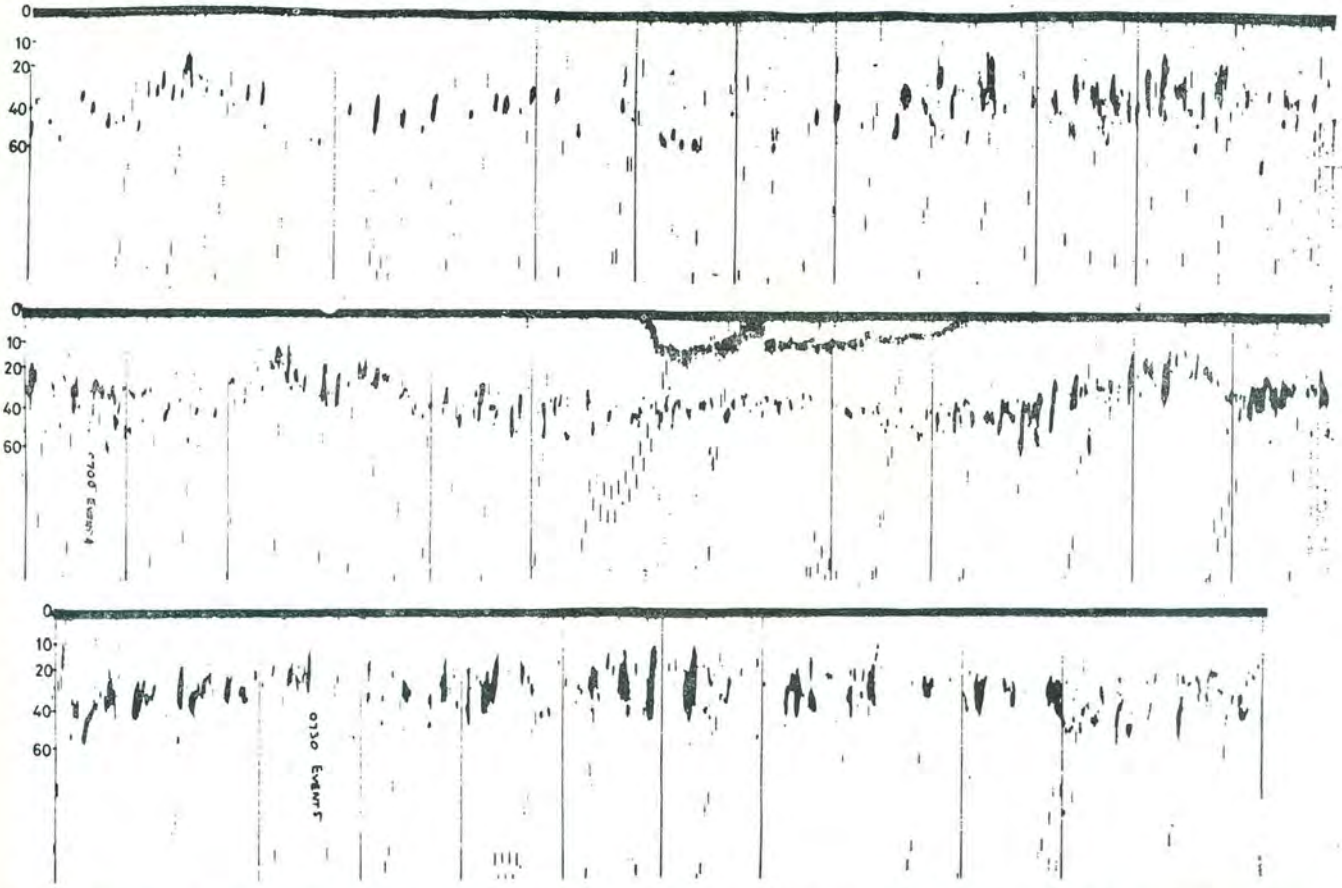


Fig. 10. Example of a swarm group extending 20 nautical miles along the ship's track at 07h00 local time, ship's speed 14 knots. Note the 'ghost bottom' in the centre of the middle strip of echo paper.

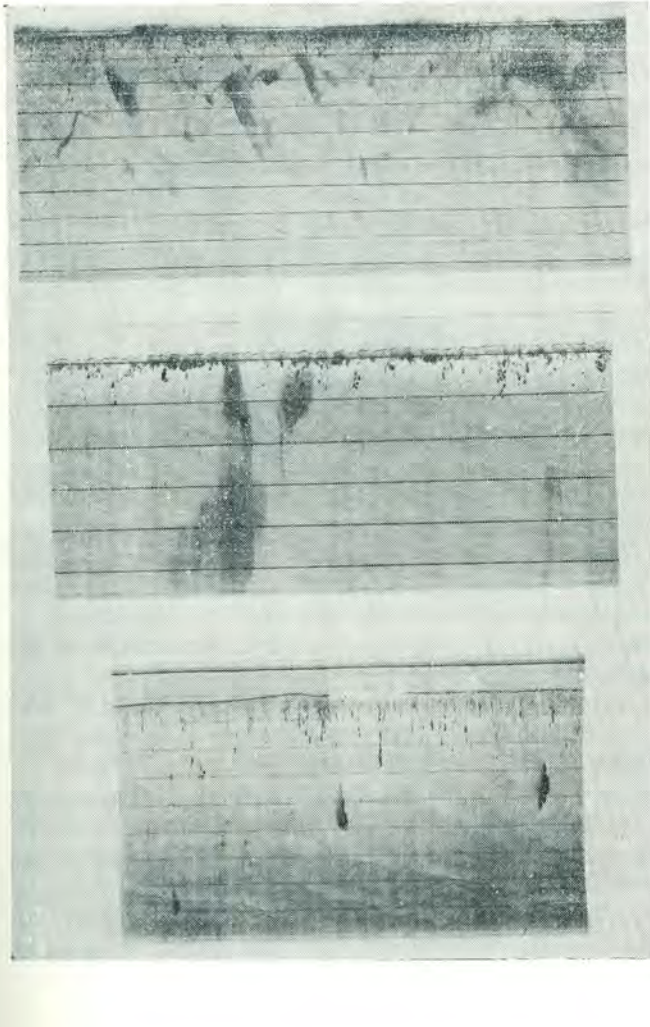


Fig. 11. Side-scan sonar recordings of krill swarms. The distance between the range markers is 15 m. The depth of the tow-fish was 15 m (approx.) and the ship's speed 3-4 knots. The echograms have not been corrected for geometric distortion.

cribe aggregations of horizontal dimension of the order of tens to hundreds of metres and with very variable thickness (Figs. 4 and 10). The term "super-swarm" is used to describe swarms of large horizontal dimension (of the order of a thousand metres or greater) and, perhaps more important, very high densities (Fig. 4c). Super-swarms were observed in the Gerlache Strait where continuous, thick, very dense swarms were located, which had horizontal dimensions of about 1 000 m. All three types were observed on occasion to be mixed horizontally and vertically, sometimes over a wide depth range.

Table 1 shows the relative abundance of krill in swarms and layers in three areas where krill was located, calculated from integrator readings. These results show that, although most of the krill was concentrated into swarms, particularly in the Gerlache Strait, the amount present in layers was considerable.

Krill swarms had a strong tendency to form "swarm groups" which extended over considerable distances. The one shown in Fig. 10 extended for about 30 km along the ship's track. Considered as entities, the swarm groups themselves exhibited a high degree of patchiness in their horizontal distribution. The two groups detected off Smith Island and the Gerlache Strait and one other small group near the South Orkney islands (61°00′ S, 49°00′ W) were the only groups detected on a passage of 1 500 nautical miles from the Drake Passage to South Georgia via the South Shetland islands (Fig. 1).

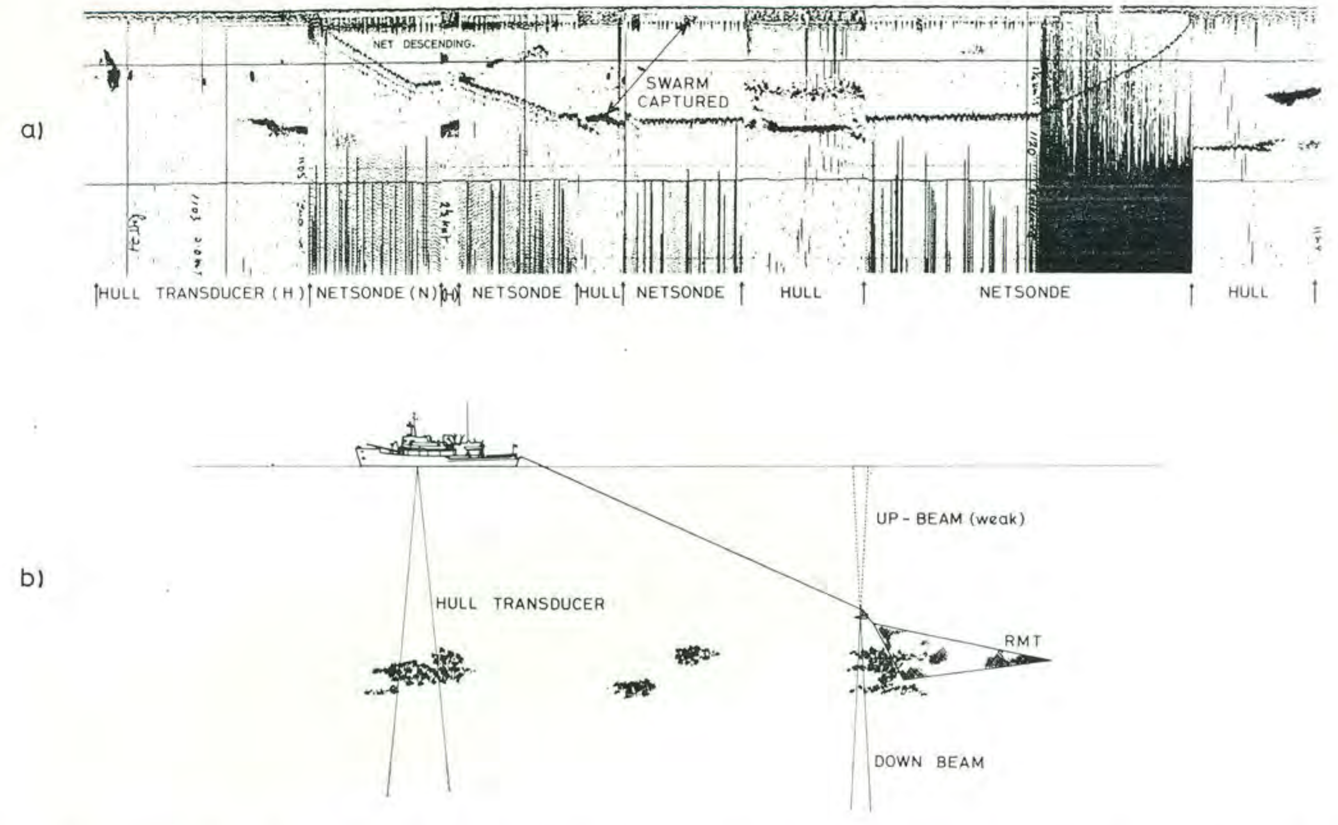


Fig. 12. Aimed RMT trawling with the 120 kHz towed transducer. 12a – the echo paper showing different recordings as it is switched between hull and towed transducers. The towed transducers' weak up-beam shows the depth of the net beneath the surface and the strong down-beam shows what is in the path of the net. By switching between hull and towed transducers the net was guided to a target (oblique trace). The dark vertical bars are produced by an electrically noisy slipring in the cable winch. 12b – a diagram of the system.

Table 1

Relative abundance of krill in different aggregation types

Locality	Total Corrected Echo-Integrator Deflection (MM)			Percentage Total Deflection		
	swarms	layers	classified as neither	swarms	layers	classified as neither
Smith Is.	788	296	323	57	19	24
Gerlache S.	2 633	143	333	82	5.5	12.5
Scotia Sea	186	203	6	47	51.5	1.5

The depth distribution of swarms within a swarm group can be very variable, and there appeared to be no predictable daytime depth of occurrence. There was a tendency to rise towards the surface at sunset, but on the other hand, swarms were observed at the surface at noon in clear water and brilliant sunshine (cf. Figs. 4c and 4d).

The patchiness within the swarm groups themselves was a striking feature. For example, exceptionally high integrator readings were obtained from a comparatively small area (approximately 400 square kilometers) at the eastern end of the Gerlache Strait (Fig. 3). These high readings were almost entirely due to a small number of super-swarms of approximately 1 000 m horizontal dimension and about 10 metres thick (Fig. 4c). The integrator readings from some of these super-swarms was higher than the accumulated reading for the 1 000 nautical mile transit between the Gerlache Strait and South Georgia.

Initial calculations indicate that the volume backscattering strength of the swarms at 120 kHz ranged from a maximum of -20 dB to a minimum of -40 dB. The layers were, in general, weaker targets, having volume backscattering strengths ranging between -25 and -45 dB. No experimental data are available on the target strength of individual krill, but a rough theoretical calculation suggests a target strength in the region of -70 dB at 120 kHz, which would place the volume densities between 1 and 100 kilograms per cubic meter for swarms and between 0.3 and 30 kilograms per cubic metre for layers. It is emphasised that these figures should be treated with caution, particularly as the target strength value assumed is not based upon experiment, but it is encouraging that the densities obtained are of the same order of magnitude as densities reported for net catches (Marr 1962, Moiseev 1970, Makarov *et al.* 1970, Nemoto & Nasu 1975).

The 100 kHz side-scan sonar was effective in detecting swarms at ranges of up to 140 m. The high spatial resolution of the system provided a good indication of the variety in swarm shapes and sizes (Fig. 11). The system could not detect layers effectively.

Phytoplankton (Ocean Colour)

There has been substantial interest in the use of the Coastal Zone Colour Scanner on the satellite Nimbus 7 as a means of measuring ocean colour, from which inferences about phytoplankton distribution and abundance can hopefully be drawn. As opportunities for spectroradiometric studies in the Southern Ocean are rare, it was decided to make measure-

Table 2

Chlorophyll data from the "noon" stations

Station No.	Date	Position	Surf. Temp.	Surf. Chl.*a* mgm/m³	Max. Chl.*a*	At depth (m)	Station	Date	Position	Surf. Temp.	Surf. Chl.*a* mgm/m³	Max. Chl.*a*	At depth (m)
16	28.2.78	55°27′S 66°01.3′W	8,8	1,0	1,0	0	27	16.3.78	63°56.4′S 61°39.6′W	–0,1	1,0	1,3	10
17	1.3.78	58°45′S 64°29′W	3,8	0,1	0,1	0	28	17.3.78	62°32′S 59°04.5′W	0,8	1,7	1,7	0
18	2.3.78	61°51.8′S 62°48.4′W	1,9	0,2	0,3	30	29	18.3.78	61°03.7′S 54°13.5′W	0,8	0,3	0,8	10
19	3.3.78	62°26.5′S 62°24.9′W	1,6	0,4	0,6	40	30	19.3.78	59°18.6′S 48°37.6′W	1,1	0,0	0,5	60
20	4.3.78	62°14.5′S 62°01.5′W	1,6	0,2	0,3	80	31	20.3.78	58°01.1′S 44°26.7′W	1,5	0,3	0,5	20
21	7.3.78	63°09.8′S 62°29.2′W	1,2	2,4	2,4	0	32	21.3.78	56°26.1′S 40°09.3′W	2,4	0,4	0,7	20
22	8.3.78	62°37.3′S 64°22.2′W	1,4	0,5	0,5	0	33	22.3.78	54°30.6′S 35°47.6′W	3,2	1,6	1,6	0
23	9.3.78	62°29.5′S 63°31.8′W	1,3	0,5	0,7	50	34	25.3.78	54°04.2′S 36°32.3′W	3,3	1,6	1,7	10
24	10.3.78	62°34.9′S 62°52.2′W	1,0	0,5	0,7	40	35	28.3.78	53°53.6′S 37°21.5′W	3,2	2,8	2,8	0
25	13.3.78	63°35.1′S 61°39.3′W	0,5	1,1	1,7	50	36	30.3.78	51°39.5′S 41.25.6′W	3,6	1,2	1,2	0
26	15.3.78	64°01.3′S 61°47.9′W	0,1	2,3	2,3	0	37	31.3.78	49°36.3′S 44°48.7′W	7,8	0,4	0,9	30

ments of ocean colour and to collect appropriate oceanographic data for comparison.

Methods

Every day throughout the cruise an "ocean colour" station was attempted at local noon, weather permitting. At each station a Secchi disc extinction reading was taken and bottle samples collected at discrete intervals, usually up to 50 m, for salinity, temperature, chlorophylls (acetone extraction), phytoplankton samples and particle size and count (Coulter counter). A continuous profile of *in vivo* pigment fluorescence and light scattering was obtained to usually 80 m.

The helicopter-borne spectroradiometer was used to take spectra from the station position and from two positions adjacent to it. A spectrum of the incident light was taken from the ship's deck either immediately before or immediately after the helicopter flight.

Results

Twenty ocean colour stations were made in the Southern Ocean (defined as the zone south of where the surface temperature changes rapidly from about 8° C to about 3° C). These data are not yet fully analysed, so it is not known if all will be of use. Chlorophyll values ranged from zero to 2,8 mg/cubic metre, and on only three occasions were values greater than 2,0 mg/cubic metre recorded. In each case the station occurred near an island. The chlorophyll data are listed in Table 2.

An ocean colour spectrum from the upper end of the scale is shown in Fig. 9a. This station was between Smith Island and Low Island (63°09,8′ S, 62°29,2′ W) in the Bransfield Strait, and the surface chlorophyll *a* value was 2,4 mg/cubic metre. The lower end of the range is shown in Fig. 9b from the open ocean at 59°18,6′ S, 48°37,6′ W. The surface chlorophyll *a* was zero and the maximum value at the station was 0,5 mg/cubic metre at 60 m.

Throughout the cruise the chlorophyll values were disappointingly low, but these data may be of value to those involved in Southern Ocean aspects of ocean colour/phytoplankton research using the Nimbus 7 Coastal Zone Colour Scanner.

Land and land/water margin features

At South Georgia, a flight series was accomplished over kelp beds and macaroni penguin (*Eudyptes chrysolophus*) and king penguin (*Aptenodytes patagonicus*) rookeries.

Kelp

Spectra and colour infrared photographs were obtained at various localities in Cumberland East Bay from fjord water, kelp beds, the beach and adjacent land vegetation. Provided that the LANDSAT 2 data contain imagery of the area from which these data were collected, it may be possible to determine the value of satellite data to a kelp survey at South Georgia and, on a larger scale, in the Southern Ocean as a whole.

Penguins

A number of oblique colour infrared and black/white photographs were taken of macaroni and king penguin rookeries. The macaroni rookery near Hercules Bay (54°06′ S, 56°39′ W) is about 2 500 m long and extends from relatively flat platforms near the sea to an altitude of about 250 m up a steep cliff. This disposition is ideal for oblique photography, but highly disadvantageous to vertical techniques. Vertical photography or spectroradiometry was not possible due to air turbulence associated with the mountainous coastline. If this choice of nesting site is typical for krill-eating macaroni penguins, then they represent a poor subject for census by satellites, as a substantial change in the area covered by or affected by nests on a steep cliff face is unlikely to be reliably measurable.

Two king penguin rookeries in the Bay of Isles (54°03′ S, 57°20′ W) were photographed with colour infrared and black/white film. Here, the nesting area was on undulating slopes quite suitable for vertical techniques, but the area of brooding birds was quite small in comparison with the area of natural vegetation preferred by them. If this situation is typical of king penguin rookeries, it would not be easy to use satellite data for a census as it appears difficult to distinguish the area occupied by brooding birds from the area preferred by them, but left vacant.

The satellite data will be examined for evidence of these three rookeries. In addition, a search will be made for the presence of other rookeries, well-known through investigation by other institutes.

Conclusions

Krill aggregations have been described in terms hitherto used mostly for pelagic fish. The object has been to use familiar terms, so that emphasis is laid upon similarities between krill and fish species commonly surveyed acoustically, rather than upon their differences. The terms are not new; for example, "super-swarm" was used in 1952 (Cushing *et al.* 1952), and its use, together with the term "swarm group", is recommended to reduce the ambiguity of description possible through the application of the terms "swarm" and "layer" to aggregations of widely differing structure.

Data collected during this cruise suggest that a survey method involving day-time visual, or other remote observations, coupled with shipborne acoustics, would have no useful role in the estimation of krill stock size. Under favourable conditions, aerial observations of krill swarms could be most useful to studies of krill swarms, particularly of their behaviour. The difficulty experienced in visually detecting the super-swarms which were detected acoustically near the surface in the Gerlache Strait illustrates the principal problem. It appears that to be detected by eye, the top of a krill swarm must be within the first few metres of the water column. Those swarms which were seen by eye were quite readily detected, but the measurements made with the spectroradiometer suggest that the sensitivity and spatial resolution of any optical device would have to be very good if krill are to be reliably detected with remote sensors.

Apart from the difficulty of discriminating subtly-coloured swarms from the colour of the sea, the greatest disadvantage to a remote sensing investigation of krill is the small size of their swarms. The Nimbus 7 Coastal Zone Colour Scanner has good spectral resolution, but even so, the spatial resolution is only 825 x 825 m. On the basis of the observations made on this cruise, the probability of detecting krill swarms with this device seems small.

An aerial night-time survey was not evaluated and neither were any measurements made on bioluminescence. This requires further attention, as survey methods based upon bioluminescence detection have been fairly extensively used in other areas (Squire 1972, Cram 1977, Zapata 1977).

Krill is a good subject for acoustics survey. Firstly, they have good sound-scattering properties at the frequencies commonly used in hydroacoustic surveys. Secondly, as krill swarms occur fairly near the surface, high frequency echo-sounders can be used without encountering problems with range. Thirdly, identification of acoustics targets is no problem due to the apparently low level of species mixing, and the ease of capture with small research nets.

The use of sonar as a survey tool needs careful investigation. The high-frequency sonar used on this cruise detected swarms at ranges up to 150 m, but was ineffective in detecting layers. Low frequency, long-range sonars may be able to detect swarms at a greater range, the main question being whether the reduced absorption of sound at the lower frequencies will more than offset the effects of the lower target strength of krill at these frequencies. Longer detection ranges would increase the possibility of defining large features such as layers, which is important, as a substantial proportion of the krill could be aggregated in this way (Table 1).

Acoustic surveys of krill with hull-mounted transducers will produce negatively biased results if the swarms are shallower than the transducer for a significant proportion of the time. The ship- and helicopter-borne echo-sounders indicated that this was the case even during daylight hours on certain occasions during the cruise.

Considering the storage and processing of acoustic data: a digital data logger proved very suitable for collecting data from swarms as highly selective logging was possible, and detailed processing made easy. However, such systems lose selectivity on layers and thus may collect an unmanageable amount of data. On-line analogue echo-integrators are generally more suitable for layers, but a survey system must have some means of electronic data storage so that noise interference can be removed on subsequent processing. Noise is a serious problem for analogue echo-integrators.

Aimed RMT was a good system for rapidly establishing the identity of acoustic targets. The use of the 120 kHz towed transducer was a highly cost-effective substitute for a net-sounder, although it did not possess many of the functions of commercially available netsounders. In retrospect, it is apparent that no "identification" haul needed to have taken more than 30 minutes from shooting to retrieval.

The prospects look poor for censusing krill by satellite observations, but for other elements of the Southern Ocean ecosystem the prospects look better. Kelp, being temporally stable, is a relatively good prospect, being only dependent upon a reasonable amount of clear sky for successful observations to be made. Penguins, on the other hand, can best be surveyed during specific periods when, for example, breeding activity is at a peak or juveniles collect in clearly defined "creches". This is a highly specific temporal requirement, making cloud cover a very critical factor in the success of a census. The choice of nest site and rookery size may also be problematical, but this aspect awaits analysis of the NASA data.

Recommendations on methods for surveying krill

1. The value of night-time remote sensing work on krill bioluminescences should be investigated, because a suitable observation system would have a valuable application to survey strategy development and to biomass estimates.
2. A solution to the problem of detecting krill concentrations occurring above the hull-mounted transducer or below the calibrated range of a high frequency transducer could be to tow upwards- and downwards-looking transducers at a suitable depth. Some of the relative advantages and disadvantages of towed and hull-mounted transducers are listed in Table 3.

Table 3

Some characteristics of towed and hull-mounted transducers

	Avantages	Disadvantages
Hull-mounted	Inexpensive installation. No problems with cables or towing gear. Can be used at high speed	Dependent upon ship's noise. Cannot replace transducers at sea (usually). Calibration difficult and/ or expensive. Shallow swarms avoid ship. Range limitation severe at high frequencies. Cannot detect swarms above the transducer.
Towed	Independent ship's noise. Transducers easily changed at sea. Calibration simple. Correctly designed surface vehicle eliminates problems of avoidance by swarms. Can be towed at depth, close to targets. Upward- or downward-looking transducers (or both) can be used.	Expensive installation (cable winch). Cable problems exist but could be solved. Towing speed limited (?).

3. Experience with the echo-integrator and digital data-logger during this cruise has shown that any echo-signal storage system should be capable of:
   (a) sampling echo-signals over a wide depth channel, minimally 150 m (see Fig. 4d),
   (b) storing echo-signals from this channel between transmissions to allow subsequent detailed analysis and noise removal.

   A system will have to be developed which samples the echo envelope sufficiently to extract vertical density profiles, without generating an unmanageable amount of digital data at the same time. This could be done by real-time software integration of the digital samples for short periods corresponding to intervals of, for instance, 20 cm in the water column. Only the integrated values from each transmission need then be stored. An option could be provided for storing all the digital samples in cases where exceptionally detailed information is required. There are sufficient analogue data on tape from this cruise to test various systems and to draw up a specification for a suitable data-logging system for krill.

   Detailed analysis of echoes would have to be performed at the end of the cruise, but some type of real-time display of relative abundance will need to be available for updating survey strategy whilst the cruise is in progress. This could be arranged by accumulating the integrated values for each transmission for each depth sub-interval, and printing out the totals at regular time or distance intervals.
4. The estimation of krill abundance is made difficult by the large "krill area" to be surveyed, approximately 20 million square kilometres (Mackintosh 1972), and by the uneven distribution of the population within that area. The acoustics data from this cruise strongly suggest that krill horizontal distribution is likely to be extremely patchy, both on a large scale (distribution of swarm "groups") and on a smaller scale (patchiness within the swarm "groups" themselves). In a stepwise approach to abundance estimates of krill, the first step should be a study of the circum-polar distribution and its gross variability, followed by the development of a purposeful survey strategy concentrating effort into areas of high abundance at the expense of area of low abundance. Ideally, the large-scale patchiness problem should be overcome through an extensive search, after which intensive surveys would be made upon each swarm group. However, logistical problems may force the use of a simpler strategy.

   If the logistical problems of mounting a circum-polar survey can be solved, then the data should provide a good description of the distribution of krill at that particular time of year. Assuming that target strength measurements of krill have been accomplished by 1981, an estimate of the absolute abundance could be made, though it is doubtful if the accuracy would be better than an order of magnitude. On the other hand, the relative abundance (in arbitary units) would be a useful measure with which to monitor future changes in stock size and its distribution.

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