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Analysis of Krill Distribution in the Bransfield Strait and Drake Passage by Means of Hydroacoustic Survey, During SIBEX I and II

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INTRODUCTION

In spite of many studies on krill distribution and biomass, *e.g.* Marr (1962), Everson (1977), Doi and Kawakami (1979), Witek *et al.* (1981), Guzman (1983), gaps in the knowledge of krill stocks persist. For this reason SCAR stimulates the continuation and expansion of investigations on the biology, ecology, population dynamics and stock assessment of krill and other potentially important Antarctic marine organisms (El Sayed, 1977).

Hydroacoustics have been effectively used to estimate krill abundance (Kalinowski, 1982; Lillo & Guzman, 1982; Hampton, 1983; Klindt & Zwack, 1984; among others). Everson (1983) pointed out advantages of this method: fine depth discrimination, large areas covered in reasonable time and effectively complete sampling along a transect. On the other hand, the main difficulty is that we cannot differentiate the specific patterns of a krill swarm on the echochart when several species are present.

Starting the research activities in the Antarctic region, the Institute of Oceanography of the University of São Paulo participated in the SIBEX expeditions, aboard its ship *R/V Prof. W. Besnard*. The studies were carried out in waters of the Bransfield Strait and Drake Passage during the austral summers of 1984 and 1985.

Preliminary results of hydroacoustic studies, geographical and vertical distributions of krill are presented. Net sampling (IKMT and Bongo net) was carried out to identify the targets in various concentrations detected by the echosounder.

MATERIAL AND METHODS

The study area, Drake Passage and the Bransfield Strait (59°S – 64°30'S and 54°W – 66°30'W), and the sampling positions were established by the SIBEX. The first expedition included 46 and the second 44 hydrographical stations (Figs. 1a, b).

Continuous hydroacoustic profilings were made along the area of investigation with an echo-souder SIMRAD EK-400 operating at the frequency of 120 kHz. An echo-integrator SIMRAD QD was connected to the echo-sounder. During the first cruise (1984), intercalibration was done with the Polish R/V *Prof. Siedlecki,* at Admiralty Bay, near Arctowski Station (King George I.). During the second cruise (1985) the equipment was calibrated by means of copper spheres (Foote, 1982, 1983) at Deception I. Although the echo sounding system allowed observations starting at 3 m, the adopted range of observations was 6-250 m (to avoid noise problems), and the integration for each 1 nm. Methodology recommended in BIOMASS Report Series no. 37 (1984) was used to calculate krill biomass. Water for salinity analysis was sampled with Nansen bottles and reversing thermometers were used for temperature measurements.

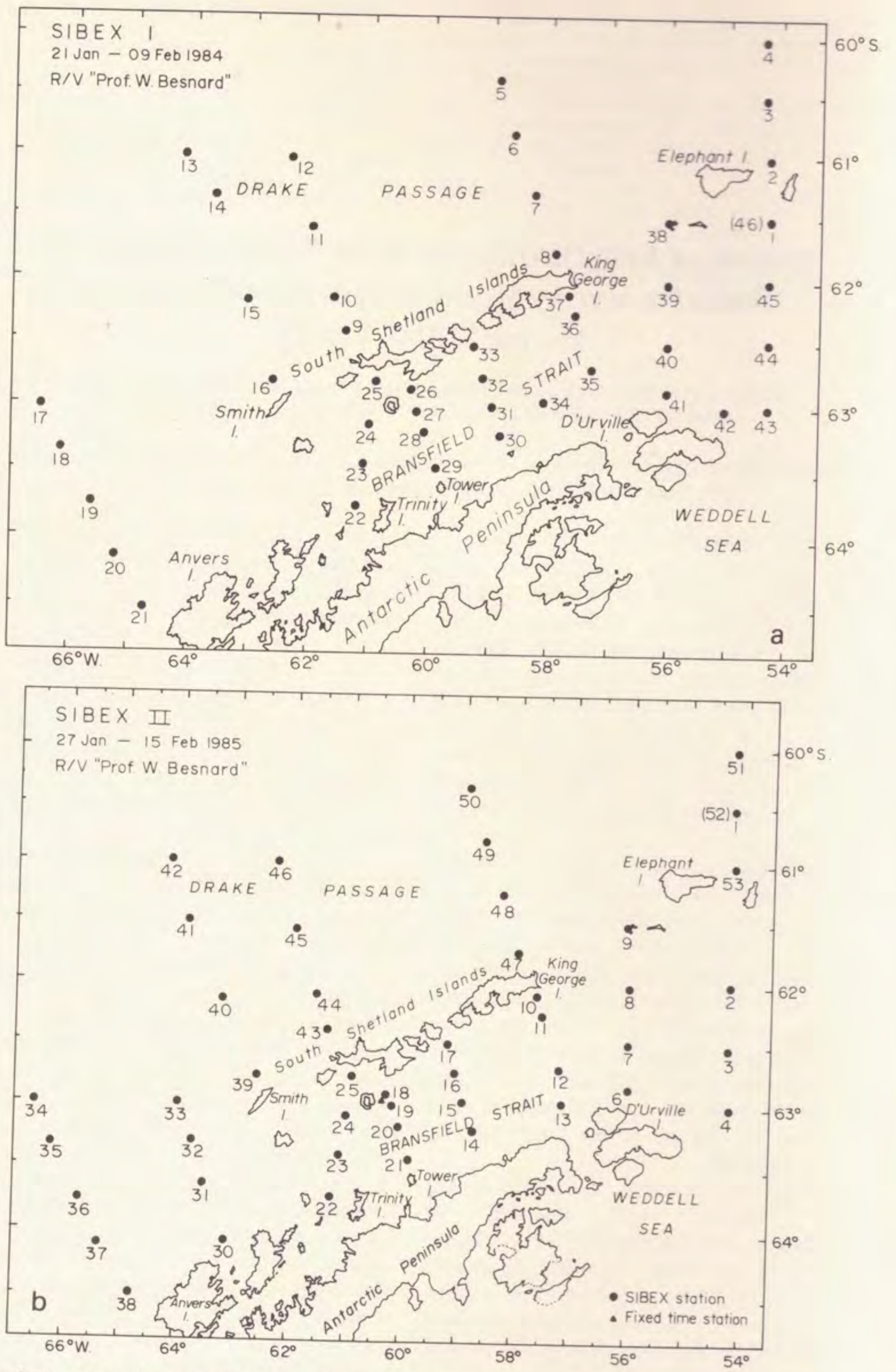
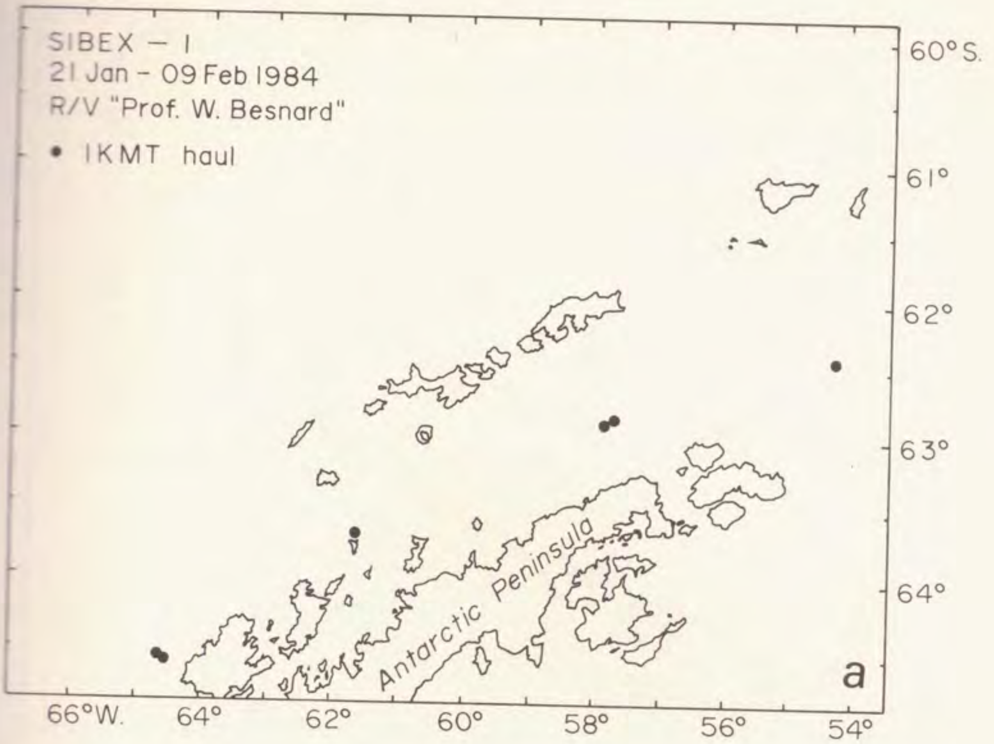


Fig. 1 – Station plan and survey area of the R/V "Prof. W. Besnard", during SIBEX I (a) and SIBEX II (b) expeditions. The positions of hydrographic stations (●) were established by SIBEX. The fixed time station (▲) was specially planned by Institute of Oceanography of University of São Paulo.



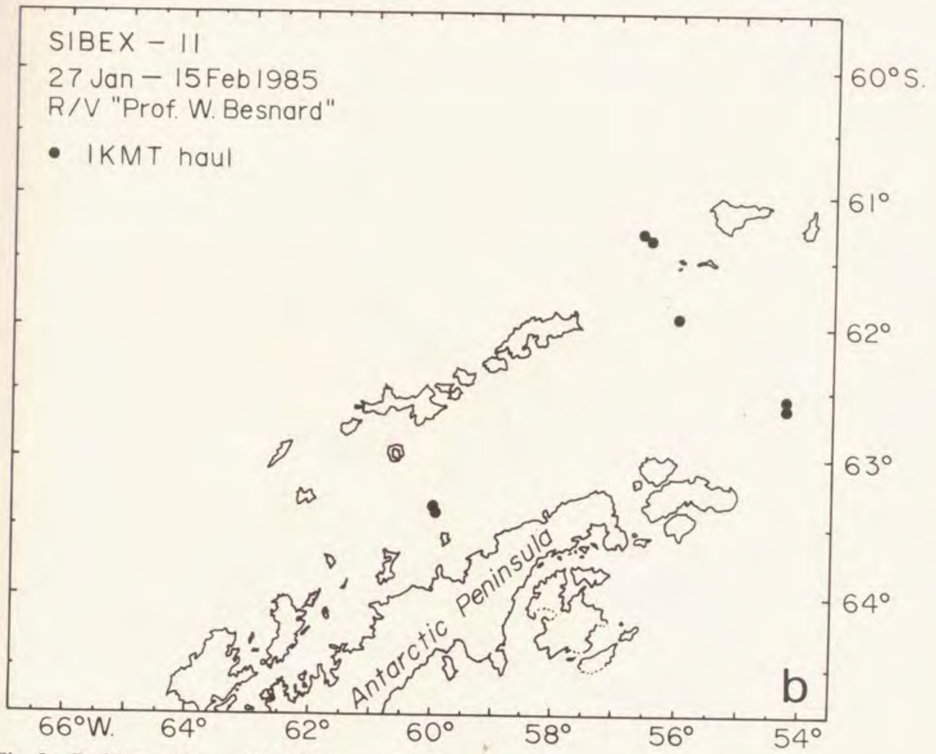


Fig. 2 – Positions of Isaacs-Kidd Midwater Trawl (IKMT) samplings, during SIBEX I (a) and SIBEX II (b) cruises.

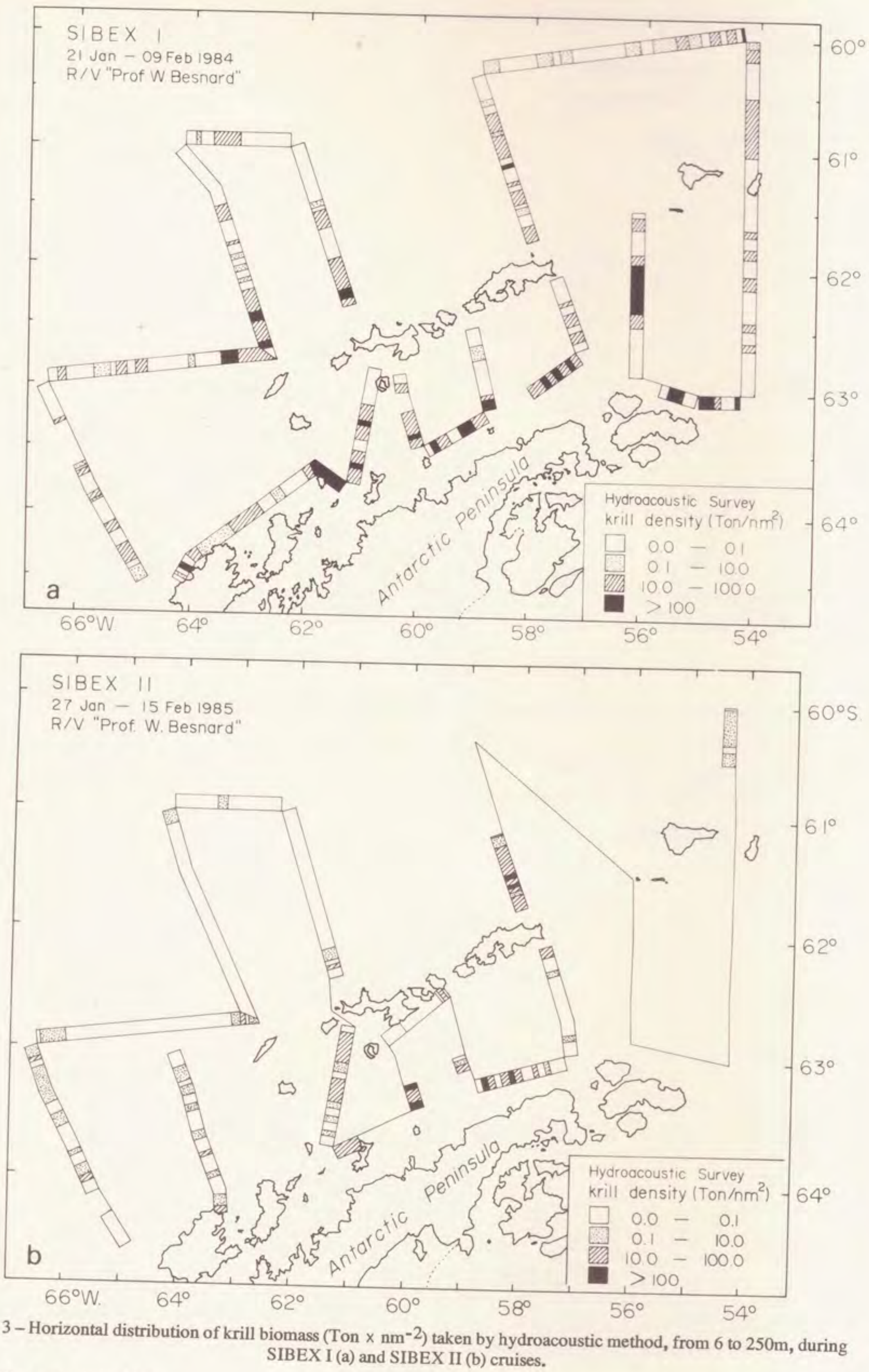


Fig. 3 – Horizontal distribution of krill biomass (Ton × nm^{-2}) taken by hydroacoustic method, from 6 to 250m, during SIBEX I (a) and SIBEX II (b) cruises.

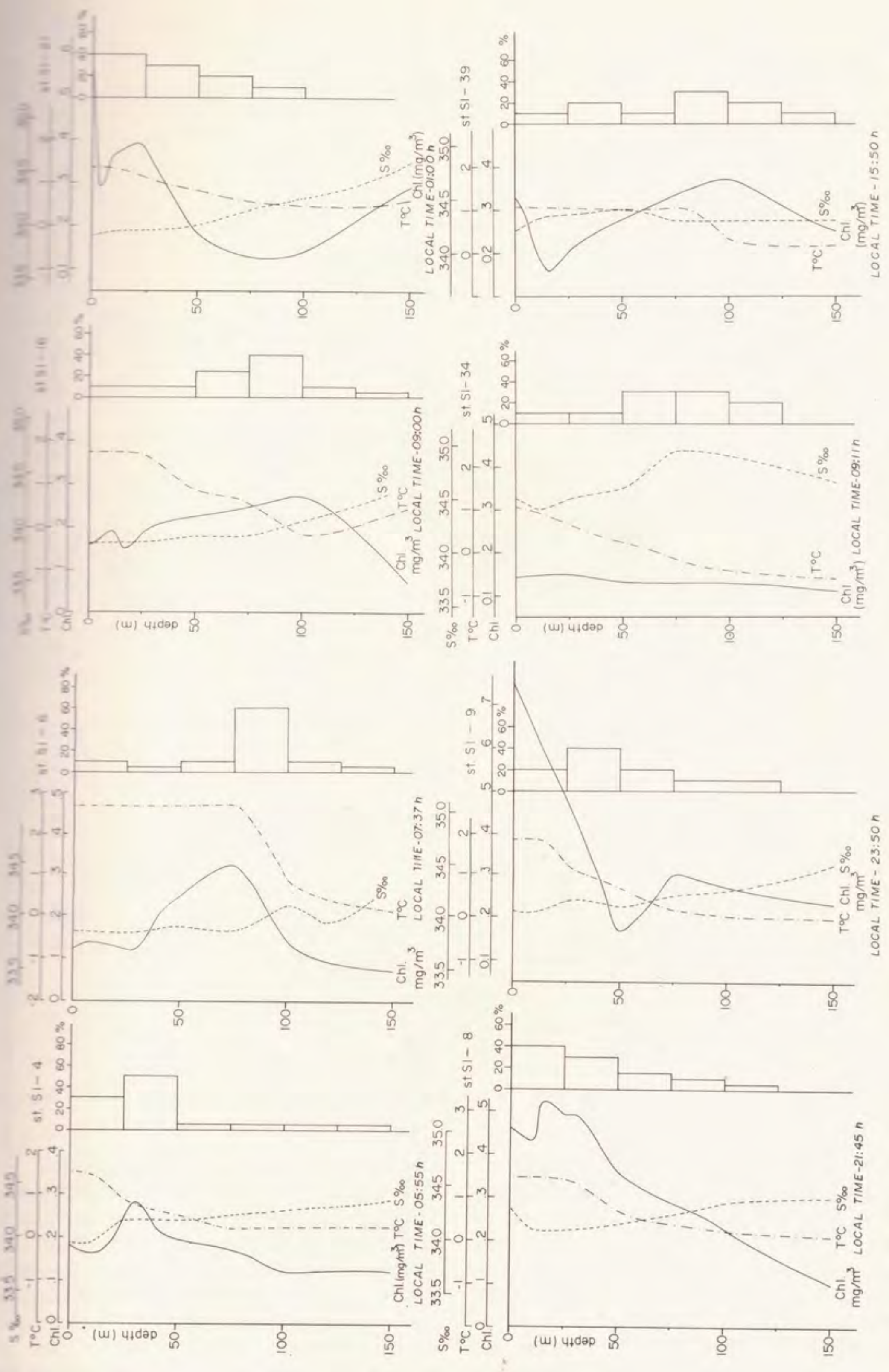


Fig. 4 – Vertical distribution of krill swarms and vertical of temperature (.–.–.–.–.), salinity (– – – –) and Chlorophyl contents in mg x m^{-3} (———), at 16 stations during SIBEX I and SIBEX II.

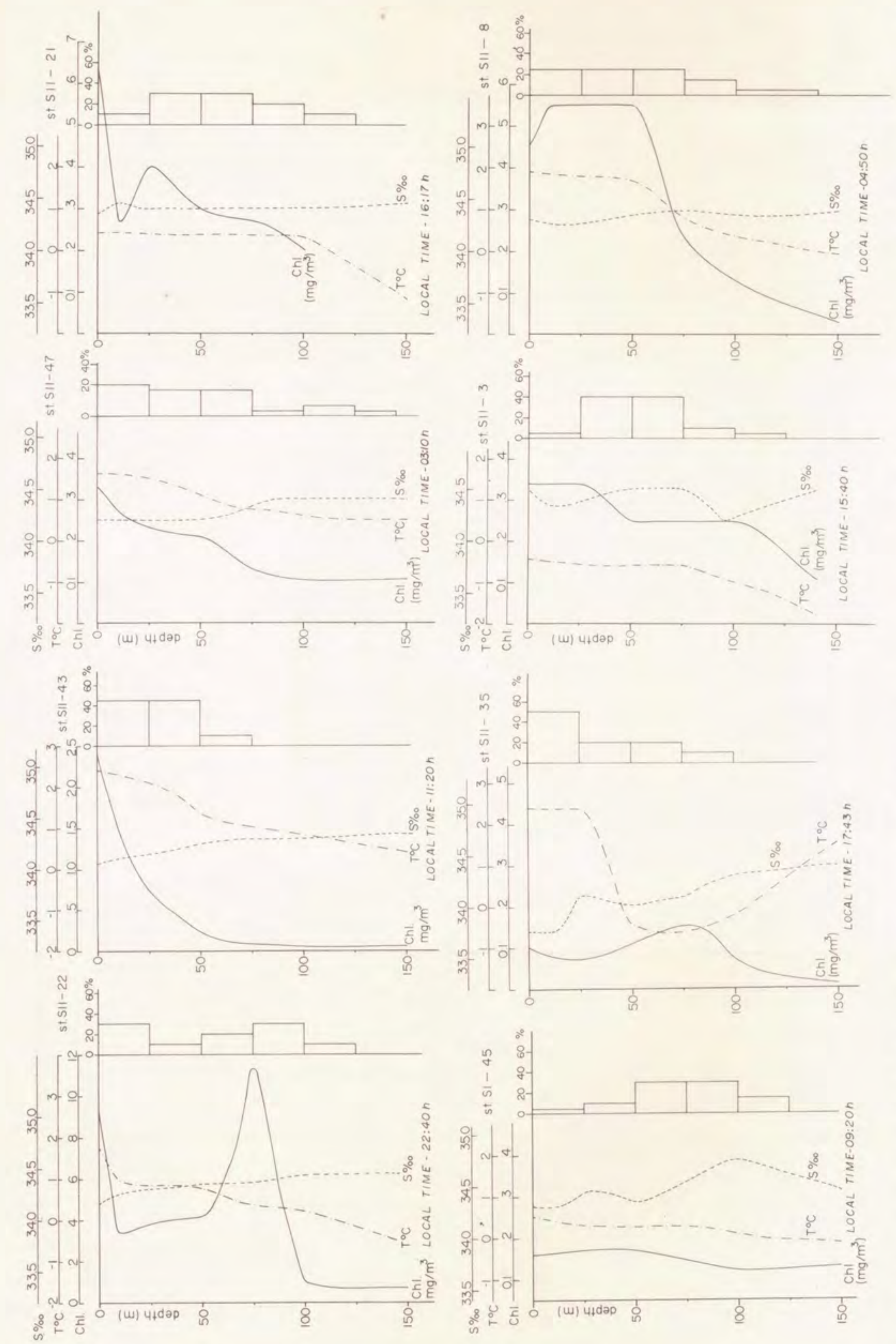


Fig. 4 (Continuation) – Vertical distribution of krill swarms and vertical of temperature (.- . - . - . -.), salinity (- - - - - - - - - -) and Chlorophyl contents in mg x m^{-3} (————), at 16 stations during SIBEX I and SIBEX II.

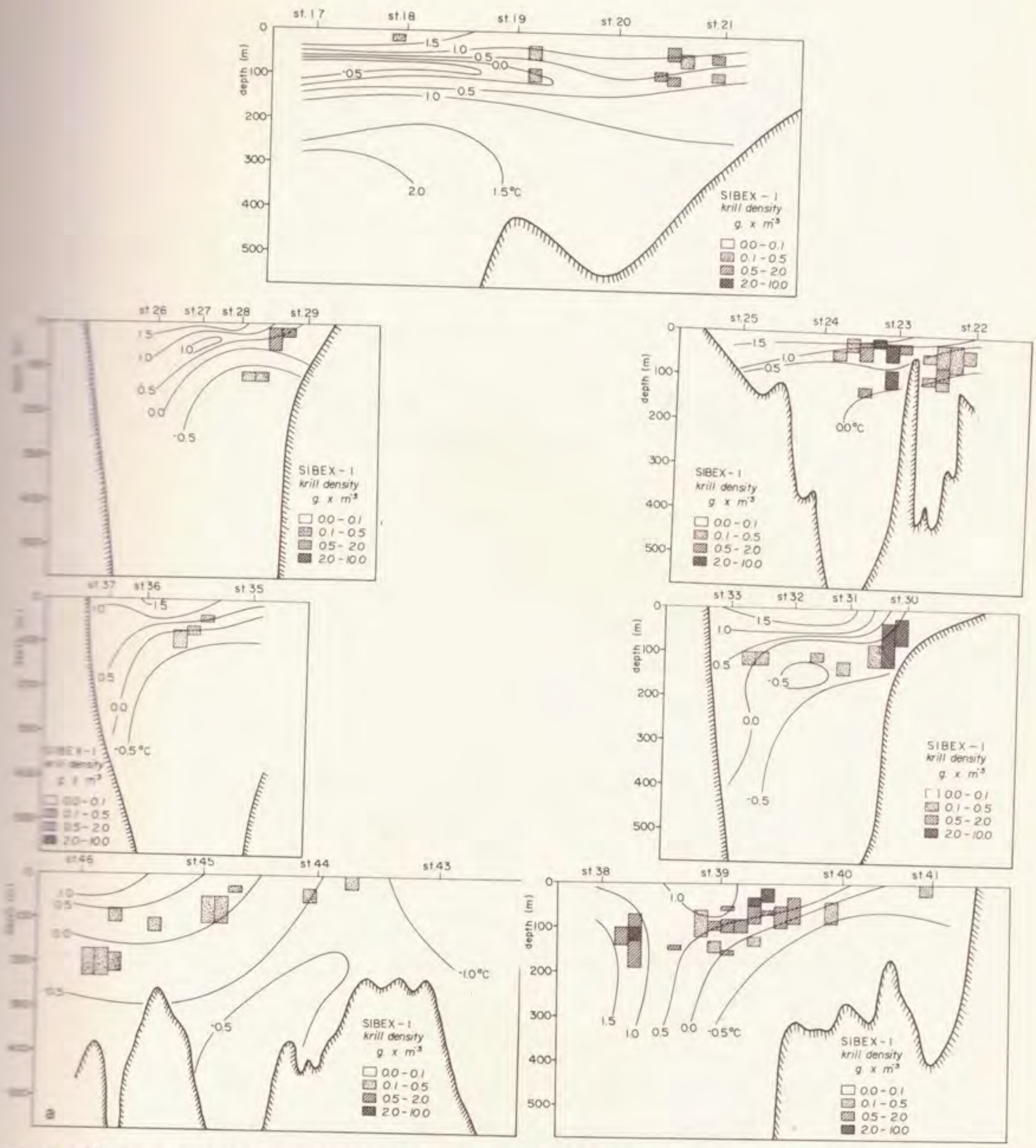


Fig. 5a – Vertical distributions of temperature and krill density (g x m^{-3}) in 17 transects, during SIBEX I (a, b) and SIBEX II (c).

The Isaacs-Kidd midwater trawl (IKMT) (Isaacs & Kidd, 1953) used had a length of 9 m, mouth open area of 8 m^2 and 25 mm mesh size. It operated when swarms were detected by the echo-sounder or indicated by a Bongo net catch of krill in the station (Fig. 2). Hauls were made horizontally, at 2-4 kn, for about 15 min. The material collected was subsampled aboard, immediately fixed with buffered formaline and stored in 1000 ml polyethylene jars. The Bongo net (McGowan & Brown, 1966) with 0.300 mm and 0.500 mm mesh size was used in double oblique tows at the stations (Fig. 1), according to the methodology described by Smith & Richardson (1977). The material collected by the Bongo net was used only to check the presence of krill.

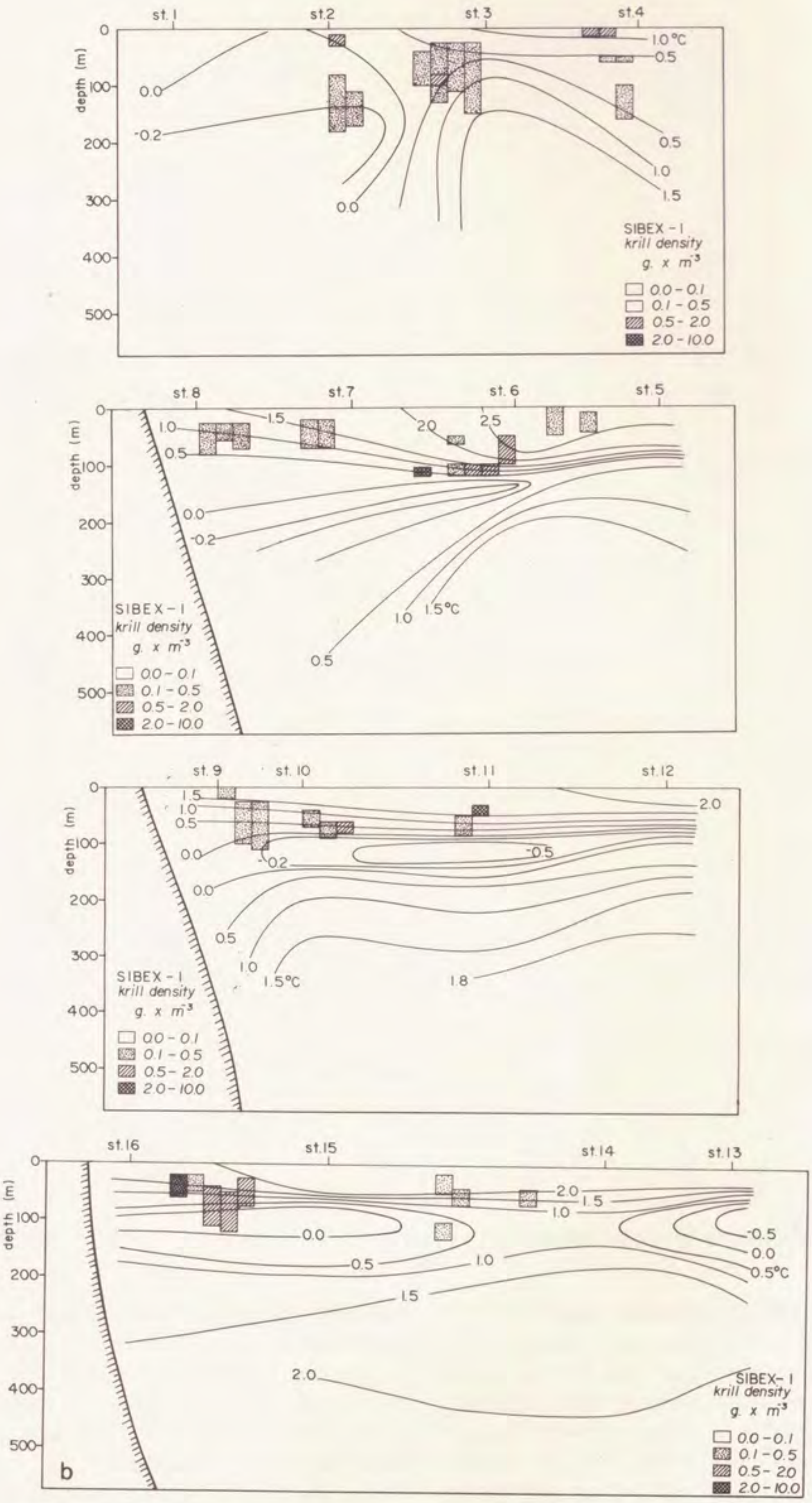


Fig. 5b – Vertical distributions of temperature and krill density (g x m^{-3}) in 17 transects, during SIBEX I (a, b) and SIBEX II (c).

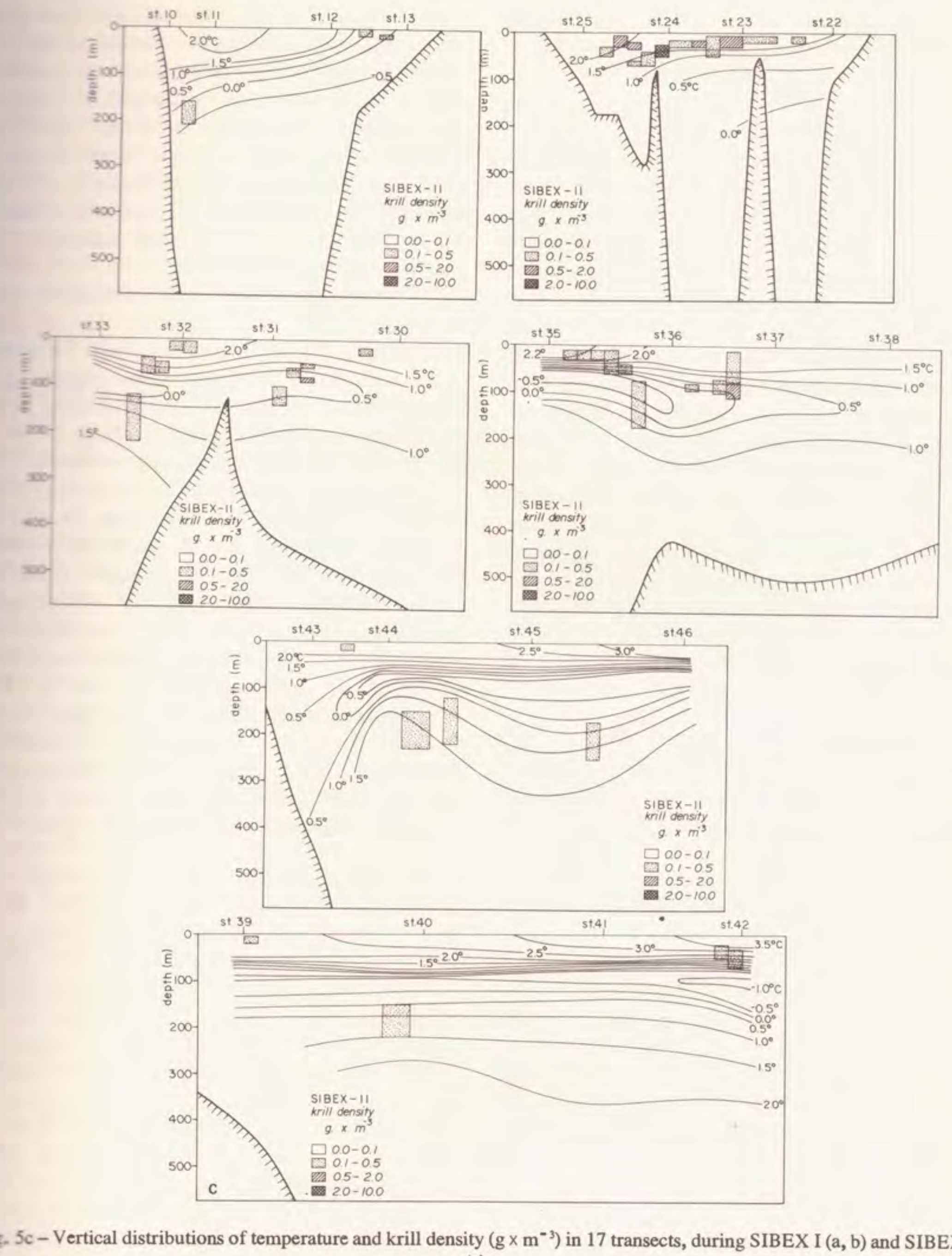


Fig. 5c – Vertical distributions of temperature and krill density (g x m^{-3}) in 17 transects, during SIBEX I (a, b) and SIBEX II (c).

To estimate the size composition of krill swarms, some individuals were measured (in mm) from the anterior margin of the eyes to the tip of the telson, according to Mauchline (1982).

The phytoplankton biomass data (mg Chl. × m^{-3} were provided by the Subproject Plankton and Primary Productivity (unpublished data). Temperature and salinity profiles were based on data by Ikeda *et al.* (unpublished).

Krill length frequency data from net

hauls (Montu, pers. comm.) were used in calculating biomass. Mean values were 34 mm (SIBEX I) and 42 mm (SIBEX II).

RESULTS

a) *Horizontal Distribution*

Total biomass (ton × nm^{-2}) distributions taken by hydroacoustic method are shown in Figures 3 a, b. Because of malfunction of the equipment, integration was not possible for some areas during the second expedition.

In 1984 salps were found in large concentration all along the two areas; in fact, most of the biomass detected was due to this organism, specially in the Drake Passage. The richest area in krill was close to the Antarctic Peninsula, mainly between Trinity I. and Tower I., and near d'Urville I. (Fig. 3 a). Adult salps were not observed in 1985 (Fig. 3 b) and we believe that krill was the main constituent of the biomass. The sites of large krill concentration were similar to those of the first cruise. Except for an area along the north side of King George I., the Drake Passage region was poorer than that of the Bransfield Strait, in 1985.

b) *Vertical Distribution*

Vertical distribution of krill swarms, compared with the profiles of temperature, salinity and chlorophyll contents are shown in Figure 4 (the swarm distribution is given in relative terms). The observations deal only with stations in which occurrences of krill were proved by net sampling. In general, water was poor in chlorophyll content, especially in 1984, when 0.76 mg × M^{-3} was the maximum. Higher levels were found in 1985 and a maximum of 11.30 mg × m^{-3} was recorded at station 22. Temperature ranged from -1.02°C to 2.72°C and salinity from 33.76°/oo to 35.08°/oo

Figure 5 shows some transects with isotherms and krill swarms (g x m^{-3} distributions for both the Bransfield Strait and Drake Passage regions. The patterns of temperature distribution differ according to the region, but a marked gradient from 50 m to around 150 m seems to be most common.

A pattern of diurnal vertical migration, based on profiles of the first cruise, is presented in Figure 6. As much as possible salp aggregations were kept apart from the entire analysis. The quantity of swarms (percentage of the total number of observations), related to the depth is presented for every 2 hour period. A total of 676 observations was taken. The daylight period (in local time) was from 03:00 hs (dawn) to 21:00 hs (dusk). Due to the echo-sounder features the upper 3m layer could not be sampled. Largest stratification (90% of

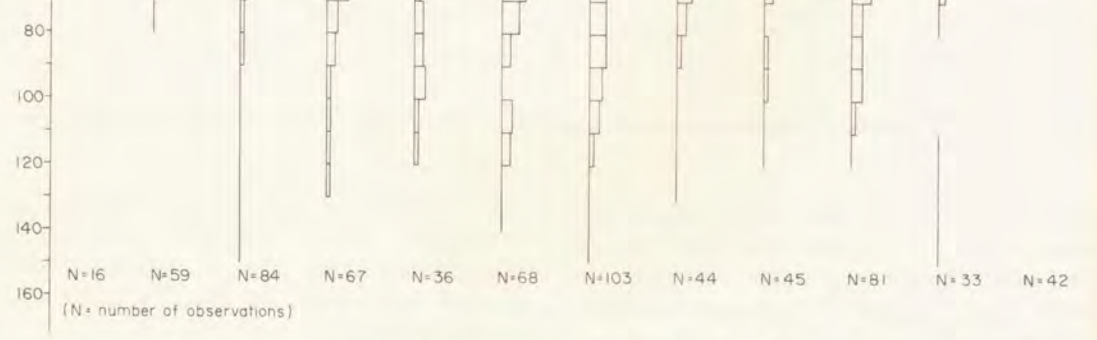


Fig. 6 – Pattern of diurnal vertical migration of krill; relative abundance by depth is given for each 2 hours range.

swarms in the upper 20 m) was observed at around 23:00 hs. At dawn (03:00 hs) a significant amount of swarms was still at the upper levels, but a downward movement could be noticed. After 05:00 hs almost all of the swarms were below 50 m and, at around 11:00 hs, the maximum lower limit was reached (90% of swarms occurred at the range 50 – 100 m). A slight tendency of an upward movement was noted in the subsequent periods and, at around 15:00 hs some swarms were concentrated on the surface strata of 30 m.

DISCUSSION

a) *Horizontal Distribution*

The observation of Everson (1983) was corroborated, *i.e.*, in the case of mixing of several species, they cannot be recognized directly by means of hydroacoustic survey alone. Mainly in 1984, salps occurred in large concentrations and a differentiation between this organism and krill was only possible after verification through net sampling. Therefore doubtful results can arise if only the hydroacoustic method is employed. It should be combined with net sampling, as pointed out by Nast (1979, 1982) and Inoue *at al.* (1985). Due to sea conditions, IKMT towing was very difficult in our case. In the Drake Passage region, the evidence of salps predominance was shown by Bongo net samplings.

Apart from that problem, some trends can be recognized. The Drake Passage region was conspicuously poor during the two cruises, Jan.-Feb. 84 and Jan.-Feb. 85. The average biomasses were 4.15 g × m^{-2} and 1.1 g × m^{-2}, respectively. These values were very low when compared with results of other authors: 24.9 g × m^{-2} (Lillo & Guzman, 1982) and 8.4 g × m^{-2} (Kalinowski, 1982).

For the Bransfield Strait region the values found were 20.6 g × m^{-2} in Jan.-Feb. 1984 and 3.1 g × m^{-2} in Jan.-Feb. 1985. Although clearly much higher than those of Drake Passage, they were low when compared with those obtained by Kalinowski (*op. cit.*) and Lillo & Guzman (*op. cit.*): 44.7 g × m^{-2} and 21.0 g × m^{-2}. The causes of this remarkable variation are not yet clearly understood. Nevertheless, it seems to be much more complex than a merely annual variation, since the above authors report different values from the same area.

Everson (1982), Piatkowski (1985), among others, found large concentrations of krill in the waters near Elephant I. In our two cruises the catches in this area were low, similar to Wormuth's (1984) observation.

In general, the results of our accoustic observations in 1984 seem very similar to those by Macaulay et al., (1984), namely very few occurrences of krill and large concentrations of salps. According to Dr. A. Mujica (pers. comm.), the Chilean expedition made the same observation. It should be pointed out that in 1985 salps were scarcely found, most of them in larval forms. Everson (1984) suggests that salps present high capacity to reproduce rapidly and form large concentrations under favorable conditions. If so, a change in these conditions might be the cause for this absence in 1985.

b) *Vertical Distribution*

An interpretation of the temperature and salinity influences on vertical distribution of krill, on the basis of only the data presented (Figs. 4, 5), is difficult. Because the knowledge of this relationship is scarce, not much literature is available. In fact, there are some recommendations for further studies to evaluate how krill concentrations vary with environmental parameters (George, 1983). Apparently, these parameters did not directly influence our findings, because krill did not show any preference for a given range of variations of these parameters (Fig. 4), as already noted by Witek *et al.* (1981). This fact may be due to the narrow range of variation of the parameters in the area surveyed.

On the other hand, the results in Figure 5 show that most of the swarms are concentrated at depths of more intense temperature gradients. Everson (1983) noted few effects of the thermocline on vertical migration. According to Witek *et al.* (1981), the presence of krill in the thermocline layer may in some cases result from its coincidence with the layer of optimum light intensity. In our case, this is not totally valid, since the same observations were made at night. Perhaps the concentration of krill swarms in that layer is not directly related to the temperature gradient itself, but to the water mass movements (ascendent, descendent, meanders or other complex movements) that originate the gradient. The tendency of krill swarms to concentrate in areas in which those movements occur has been commented on by Everson (1977). However, George (1983) states that it is still not clear which role the water mass movements play in the horizontal and vertical movements of krill swarms.

The results presented in Figure 4 suggest a strong relation between vertical distribution of swarms with photo-periods and chlorophyl contents. At night, swarms showed a tendency to concentrate in the surface layers, specially above 40 m. During daylight the swarms were widespread along the water column down to 150 m, with higher concentration between 10 and 110 m. As shown in Figure 6, most of the aggregations were found during daylight at deeper strata than at night. As the whole area of study was included, there is a possibility that different krill populations have been overlapped, what could explain the upward movement around 15:00 hs. Nevertheless, our results are in close agreement with those found by some authors, e. g. in the region between Scotia Sea and Bellingshousen Sea (Kalinowski & Witek, 1980), in the north of Orkney I. between the Bellingshousen Sea and Weddell Sea (Everson, 1983). Occurrences deeper than 150 m were rare, although Nast (1979) has observed concentrations down to 200 m.

Relation between vertical migration of krill and feeding is presented by several authors. During active feeding, according to Pavlov (1974), krill rises to the surface and disperses, comes together as swarms when is repleted, stops feeding and then descends. Antezana & Ray (1983) presented similar view and suggested that the vertical migration should be an effective mechanism to assess both vertical and horizontal variations of food concentration. These observations seem obvious since organisms must feed to survive. Our results (Fig. 4) also suggest a tendency for higher concentration of swarms in the layer of higher chlorophyl concentration. However, this occurs mainly at night time stations; during daylight it seems that krill avoids the surface, even if this layer has high chlorophyl concentration. These observations suggest that distribution of food organisms may be a main controlling factor of vertical migration of krill, but the light regime also palys a very important role.

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SUMMARY

Preliminary results of hydroacoustic surveys during SIBEX I (Jan. 21.-Feb.9.1984) and SIBEX II (Jan.27.-Fev.15.1985) cruises aboard Brazilian *R/V Prof. W. Besnard* in the Bransfield Strait and Drake Passage region are presented. Net sampling (IKMT and Bongo net) was used to identify the animals in the aggregations detected in the echocharts. Small amounts of krill were detected during both cruises. Salps were the dominant organisms during the first expedition. Influence of abiotic parameters and phytoplankton distribution on geographical and vertical distributions of krill are discussed. The vertical distribution of krill is apparently related to the phytoplankton distribution and time of the day. Combination of hydroacoustic survey with net sampling seems to be essential for an accurate study of krill swarms.

REFERENCES

ANTEZANA, T. & RAY, K., (1983), Aggregation of *Euphausia superba* as an adptative group strategy to the Antarctic ecosystem. In: SCHNACK, S. B. (ed). On the biology of krill *Euphausia superba*. Proceedings of the Seminar and Report of the Krill Ecology Group. Bremerhaven, 12-16 May 1983. *Ber. Polarforsch. Sonderh.*, **4**: 199-215.

BIOMASS, (1984), Meeting of Working Party on Acoustics to prepare for Post-FIBEX Acoustic Workshop, Hamburg, 2-6 April 1984. *BIOMAS Rep. Ser.*, **37**: 1-60.

DOI, T. & KAWAKAMI, T., (1979), Natural mortality and density in krill swarms. *Comprehensive report on the population of krill Euphausia superba in the Antarctic*. Tokai Regional Fish. Res. Lab. Tokyo, 19-33.

EL SAYED, S. Z., (ed), (1977), *Biological Investigations of Marine Antarctic Systems snd Stocks (BIOMASS)*, Vol. 1: Research Proposal. SCAR/SCOR Working group 54. 79pp.

EVERSON, I., (1977), *The living resources of the Southern Ocean*. FAO Rome. 156pp.

EVERSON, I., (1982), Distribution of krill. In: HEMPEL, G. & B. HEYWOOD (eds.), Joint Biological Expedition on RRS John Biscoe Feb. 1982, *Ber. Polarforsch.*, **5**: 1-55.

EVERSON, I., (1983), Variations in vertical distribution and density of krill swarms in the vicinity of South Georgia. In: NEMOTO, T. & MATSUDA, T. (eds). Proceedings of the BIOMASS Colloquium in 1982. *Mem. Natn. Inst. Polar Res.*, Tokyo. Spec. issue, (27): 84-92.

EVERSON, I., (1984), Zooplankton. In: LAWS, R.M. (ed.), (1984) *Antarctic ecology*. London, Academic Press, **2:** 463-490.

FOOTE, K.G., (1982), Optimizing copper spheres for precision calibration of hydroacoustic equipment. *J. Acoust. Soc. Am.*, **71** (3): 742-747.

FOOTE, K.G., (1983), Maintaining precision calibrations with optimal copper spheres. *J. Acoust. Soc. Am.*, **73** (3): 1055-1063.

GEORGE, R.Y., (1983), Krill swarms and life cycle in relation to physical and biological oceanographic parameters in the Southern Ocean. In: SCHANACK, S.B. (ed). On the biology of krill *Euphausia superba*. Proceedings of the Seminar and Report of the Krill Ecology Group. Bremerhaven, 12-16 May 1983. *Ber. Polarforsch. Sonderh.*, **4:** 9-20.

GUZMAN F.O., (1983), Distribution and abundance of Antarctic krill (*Euphausia superba*) in the Bransfield Strait. In: SCHANACK, S.B. (ed.). On the biology of krill *Euphausia superba*. Proceedings of the Seminar and Report of the Krill Ecology Group. Bremerhaven, 12-16 May 1983. *Ber. Polarforsch. Sonderh.*, **4:** 169-190.

HAMPTON, I., (1983), Preliminary report on the FIBEX acoustic work to estimate the abundance of *Euphausia superba*. In: NEMOTO, T. & MATSUDA, T. (eds.), Proceedings of the BIOMASS Colloquium in 1982. *Mem. natn. Inst. Polar Res.*, Tokyo, Spec. issue (27): 165-175.

INOUE, K.; MINE, Y.; KITAZAWA, A. & KASHIWA, T., (1985), Estimation is standing stock of the Antarctic krill population in an Antarctic area south of Australia by means of a scientific echo-sounder. *J. Tokyo Univ. Fish.*, **72** (1): 13-19.

ISAACS, J.D. & KIDD, L.W., (1953), *Isaacs-Kidd midwater trawl.* Final report. Scripps Inst. Oceanogr. (Ref. 53-3, 1-18. Oceanographic equipment rept. no. 1).

KALINOWSKI, J., (1982), Distribution and stocks of krill in the Drake Passage and Bransfield Strait, during the BIOMASS-FIBEX expedition 1981. *Pol. Polar Res.*, 3 (1-4): 243-251.

KALINOWSKI, J., (1984), The biomass of krill in the eastern part of Bransfield Strait, March 1981. *Pol. Polar Res.*, **5** (12): 99-105.

KALINOWSKI, J. & WITEK, Z., (1980), Diurnal vertical distribution fo krill aggregation in the Western Antarctic. *Pol. Polar Res.*, **1** (4): 127-146.

KLINDT, H. & ZWACK, F., (1984), A method for acoustic estimation of krill (*Euphausia superba*) abundance applied to FIBEX data. *Arch. Fisch. Wiss.*, **34** (2/3): 121-144.

LILLO, S. & GUZMAN, F.O., (1982), Estudio de la abundancia, distribucion y comportamiento del krill en el Estrecho Bransfield y Paso Drake, mediante tecnicas hidroacusticas. *Serie cient. Inst. antart. chileno*, (28): 23-55.

MACAULAY, M.C.; DALY, K.L. & MATHISEN, O.A., (1984), Acoustic assessment of the distribution and abundance of micronekton and nekton in the Scotia Sea, March 1984. *Antarctic J. United States*, 19 (5): 141-143.

MARR, J.W.S., (1962), The natural history and geography of the Antarctic krill (*Euphausia superba*). *Discovery Rep.*, **32:** 33-464.

MAUCHLINE, J., (1982), Measurement of body length of *Euphausia superba* Dana. *BIOMASS Handbook*, **4:** 1-9.

MCGOWAN, J.A. & BROWN, D.M., (1966), *A new opening-closing paried zooplankton net.* SIO Ref., 56pp.

NAST, F., (1979), The vertical distribution of larval and adult krill (*Euphausia superba* Dana) on a time station south of Elephant Island, south Shetlands. *Meeresforsch.*, **27** (2): 103-118.

NAST, F., (1982), The assessment of krill (*Euphausia superba* Dana) biomass from a net sampling programme. *Kieler Meeresforsch.*, **29** (3): 154-165.

PAVLOV, V. YA., (1974), On the relationship between the feeding habits and behavioral characteristics of *Euphausia superba* Dana. In: EVERSON, I., 1977, *The living resources of the Southern Ocean.* FAO. Rome, 156pp.

PIATKOWSKI, U., (1985), Maps of the geographical distribution of macrozooplankton in the Atlantic Sector of the Southern Ocean. *Ber. Polarforsch.*, **22:** 1-55.

SMITH, P.E. & RICHARDSON, S.L., (1977), Standard techniques for pelagic fish egg and larva survey. *FAO Fish. tech. Pap.*, (175): 1-100.

WITEK, Z.; KALINOWSKI, J.; GRELOWSKI, A. & WOLNOMIEJSKI, N., (1981), Studies of aggregations of krill (*Euphausia superba*). *Meeresforsch.*, **28** (4): 228-243.

WORMUTH, J.H., (1984), Net sampling of the zooplankton and krill in and around Elephant Island. *Antarctic J. United States*, **19** (5): 136.