Korean Journal of Polar Research 8(1, 2): 117-125

Biomass and Distribution of Krill (*Euphausia superba*) in the Bransfield Strait during the Peruvian ANTAR Expeditions I, II, and III.

Mariano Gutiérrez*

Peruvian Marine Instiute (IMARPE), Esq. Gamarra y Valle s/n, Callao, AP 22, Peru

ABSTRACT. Peruvian Expeditions ANTAR I, II, and III took place during January and February of 1988, 1989 and 1991, respectively. A series of surveys of the Bransfield Strait (Antarctic Peninsula) have been conducted by the research vessel "Humboldt". During ANTAR III, investigations were extended to the adjacent waters around Elephant Island. The same equipment and similar methodology have been used in all the surveys to reveal the horizontal and vertical distributions and biomass estimations of the krill. Results of the biomass estimations were: in ANTAR I, 17.0x10^6 ton (±29.41%) with a density of 536.05 g m^{-2}; in ANTAR II, 5.67x10^6 ton (±16.66%) with a density of 176.66 g m^{-2}; and in ANTAR III, 8.43x10^6 t (±12.0%) with a density of 200.93 g m^{-2}. Higher concentrations of krill were observed during ANTAR I between King George and Elephant Islands; during ANTAR II, between Lieja and Livingstone Islands, and also between King George and Elephant Islands; and in ANTAR III the main areas were along the Bransfield Strait and to the north of Elephant Island.

Key Words: Antarctic, krill, krill biomass, krill distribution

Introduction

As the nutritional requirements of the world population increase, so also does the need for explotation of living resources. Man, in permanent search of new sources of protein, has been systematically exploiting the stocks of Antarctic krill over the past few decades. The fishing effort on this species is increasing all the time and for this reason we must accomplish a long-term monitoring of the distribution and of the available quantity of krill, as a form of preserving the ecological balance of the Antarctic, one of whose main links is, without doubt, the krill.

Peru began its scientific activities in the Antarctic in 1988, participating in the BIOMASS program through its Surveys ANTAR. There have been seven Peruvian surveys up to the present. In the first three (*Antar I, II* and *III*) hydroacoustic studies were performed to evaluate the distribution and biomass of the krill in the Bransfield Strait (Antarctic Peninsula) and in the surroundings of Elephant Island. This work presents and analyses the results of those studies on krill.

Materials and Methods

The studies have been conducted by researchers of The Instituto del Mar del Peru (IMARPE), owner of RV Humboldt which is the ship used for the surveys. She is a research vessel of 76 m length designed for the fishing investigations of IMARPE in the Peruvian waters. The same equipment and methods have been used for evaluating the hydroacoustic data in all three ANTAR Surveys, as detailed in Table 1.

The evaluation of biomass and distribution of krill was done by the same method in all cases, using following procedure:

Calibration with live krill. In order to obtain "C" (echointegration constant for the krill) we always

*corresponding author (mgutierrez@imarpe.gob.pe)

Table 1. A list of equipments used for Peruvian Expeditions *Antar I, II,* and *III*

System of analogue echointegration
- Scientific sounder SIMRAD EK-120 kHz
- Analogue echointegrator SIMRAD QM MK-II
- Recorder Hewlett Packard 7702-B

Calibration system
- SIMRAD calibration control panel
- Cylindrical calibration cage
- External transducer SIMRAD 120 kHz

Auxiliary equipment
- Scientific sounder SIMRAD EK-38 kHz
- Net-sounder SIMRAD ET-102, 49 kHz
- Engel 988/400 trawl net, with a covered cod end having small mesh netting 5 mm for the catch of krill
- Computer
- Planimeter

applied the method described by Johannesson & Vilchez (1981). For this, we used the calibration cage, the external transducer and the analogue system of echo-integration. After capture, the krill is kept alive in tanks with circulating sea water and they are moved gradually into the cage until the readings of the echointegrator become saturated. The density of krill inside the cage increases so this constitutes a simulation of varying densities being observed in the field. "C" was determined according to the following equation:

$$C = 3.43\frac{N \cdot W \cdot \Delta R}{V(\overline{M}_0 - \overline{M}_c)}$$

where, N: number of specimens
w: average weight of krill (ton)
R: integration layer (m)
V: volume of cage (m^3)
$\overline{M}_o$: average of echointegrator readings (mm)
$\overline{M}_c$: average of echointegrator readings with empty cage (mm)

Collecting data. The ship sails at a speed of 10 knots. Trawling to identify the registrations is performed with the Engel net when there is an abundance of echo-traces. Readings from echo-integrator recorder are taken each 12 minutes (or 2 nm). Identification of the recordings was performed manually using echograms, integrams and data from the trawls .

Table 2. Categories of relative abundance according to the echointegrator readings

Category	Echointegrator reading (mm) *Antar I*	*Antar II* and *III*	Nickname
0	0	0	null
D (I)	1 to 100	1 to 10	very scattered
C (II)	101 to 1000	11 to 100	dispersed
B (III)	1001 to10000	101 to 1000	dense
A (IV)	more than 10000	more than 1000	very dense

Determination of strata. A linear stratified sampling scheme was applied according to the description of Johannesson & Vilchez (1981), in this case each stratum is 10 times greater than the one before. According to the maximum values observed for M (deflection of echointegrator in millimeters), four strata were determined for each of the ANTAR Surveys (Table 2).

File of information. The information was kept in ASCII files using statistical software developed in IMARPE to determine biomass calculations, confidence limits, vertical distributions, positions of ESDU (Elemental Sample Distance Unit), etc. The ESDU had a length, in all cases, of 2 nm.

Processing. Using the deflections file (a deflection is a "jump" of the needle of the echointegrator recorder; the magnitude is shown in millimeters due to the fact that the "jump" is a length on the record paper; there can be **n** deflections in each ESDU) with the software were calculated the average, summation, variance, etc. of values for **M** (total deflection of echointegrator during each ESDU) for each stratum and degree of longitude. The areas of distribution were delimited by contouring manually in scale charts on the areas being studied, and their magnitude (in squared nautical miles) was determined by the use of a planimeter. Thereafter the biomass was calculated according to the following equation:

$$W_B = C\sum_{1}^{n}(\sum_{j=1}^{j=4} A_j \cdot M_j)$$

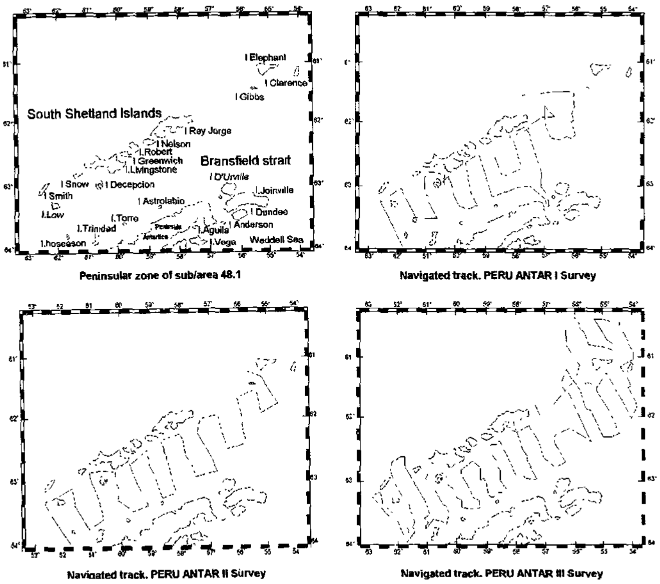

Fig. 1. Bransfield Strait and navigate tracks in the first three Antarctic surveys.

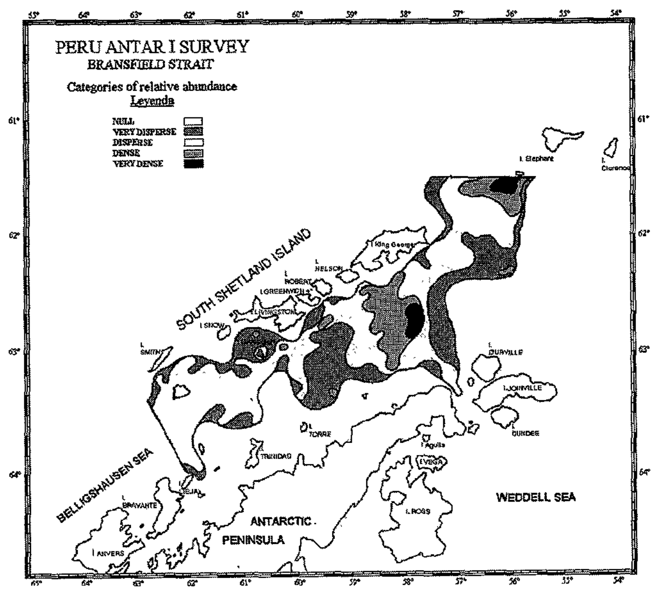

Fig. 2. Distribution of krill for categories of abundance (*Antar I*).

where, W_B: biomass (ton)
n: degrees of longitude involved in the evaluation
C: constant (ton nm^{-2} mm^{-1})
A_j: area occupied by each stratum (j) in each degree of longitude (nm^2)
M_j: averaged echo-integrator value by stratum in each degree of longitude (mm)

At the same time the vertical distribution of swarms was determined during the light and dark hours of the day (04 to 22 and 22 to 04, respectively) and the vertical distribution of **M** according to the same regime. The mid-depth of the swarm's kernel was determined from the structure of the vertical distribution. The "night-day" ratio was also calculated, from the echointegrated average for the dark hours (Cn) divide by that for the light hours (Cd). These parameters constitute behavioral indices of the krill arising from the daily regime of aggregation and dispersion. Furthermore, the confidence limits on the estimate have also been determined, using the method described by Bazigos (1976).

Results

Tracks

The cruise tracks for the Peruvian ANTAR Expeditions I, II, and III executed between the months of January and February of the years 1988, 1989 and 1991, respectively, are shown in the Fig. 1. In all the cases modifications were made to the originally planned track mainly for reasons of time or the state of the sea. The separation between the transects that constitute the track was in all cases 18 nm. Trawling to identify the echotraces was done at intervals over the cruise track.

Echointegration Constant "C"

The calculated values of "C" were 2.10, 4.13 and 2.50 ton nm^{-2} mm^{-1} for *Antar I, II,* and *III*, respectively (Table 3).

Horizontal distribution of krill

The horizontal distribution was constructed from the records of the sounder and echointegrator. It was necessary to exclude the zone between 3 and 10 nm of the Antarctic Peninsula and islands for vessel safety reasons.

Antar I. The abundance categories "very dense" and "dense" prevailed, mainly between King George and Elephant Islands. Categories "very scattered" were present in limited areas more often next to the Antarctic Peninsula (Vilchez *et al.* 1988; Fig. 2).

Antar II. Six small concentrated kernels catalogued as "very dense" were detected in front of

Table 3. Comparison of the execution features of the ANTAR Surveys

No.	Period	C (t/mm/mn²)	Executed transects	Sailing miles	Covered area (mn²)	Positive area (mn²)	Negative area (mn²)	Excutive catches	Biomass (ton)	Biomass (g m⁻²)	Confidence limit(%)
I	Jan-Feb 1988	2.10	12	908	9,546	9,246	300	3	17,000,000	536.05	29.41
II	Jan-Feb 1989	4.13	13	884	10,615	9,362	1,253	9	5,672,924	176.66	5.67
III	Jan-Feb 1991	2.50	22	1,308	16,980	12,238	4,742	10	8,434,600	200.93	12.00

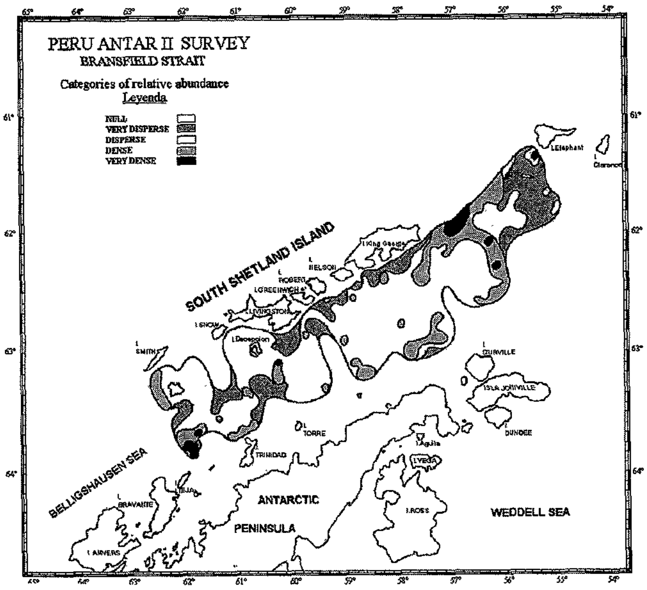

Fig. 3. Distribution of krill for categories of abundance (*Antar II*).

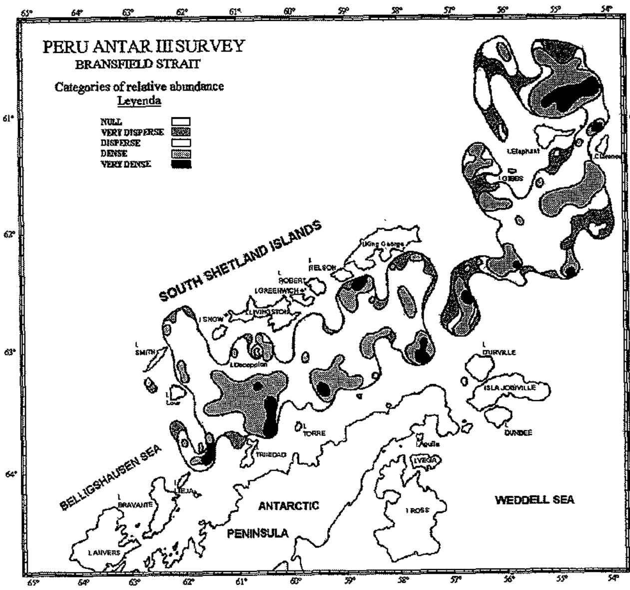

Fig. 4. Distribution of krill for categories of abundance (*Antar III*).

Lieja and Livingston Islands and between the King George and Elephant Islands. There were, aditionally, very small kernels of "dense" categories along the Strait. Also swarms of "scattered" and "very scattered" types were detected over a large part of the Strait (Vilchez *et al.* 1989; Fig. 3).

Antar III. Most of the aggregations catalogued as "very dense" were located along The Bransfield Strait, with the main concentration at the north of Elephant Island. Also, the category "dense" was distributed all along the zone of study. The categories "scattered" and "very scattered" were registered in large parts of the areas studied, mainly in the central zone of the Strait (Vilchez *et al.* 1991; Fig. 4).

Vertical distribution of krill

Here the results by number of swarms and by echointegration are presented. For all the studied area, the hours between 04 and 22 are considered as the light time, and the period between 22 and 04 hours as the dark time, corresponding to the observed day-night regime. For this distribution the 'surface line' is in fact the depth of the acoustic transducer. The echointegration is not effective in the first eight meters of depth below sea level (4.5 m offset below the vessel and 3.5 m of turbulent zone below the transducer; Figs 5 and 6).

Antar I. The swarms of krill were distributed during the day down to 230 m and at night down to 150 m. Most of the swarms congregated by day around 130 m and by night around 10 and 130 m. The greater integration was in the day around 130 m and in the evening around 120 m.

Antar II. The swarms of krill were distributed up to 100 m by day and at night. In either case, most of the swarms were in the first 10 m of depth. Regarding the echointegration, the greatest values were found between 10 and 20 m during the light

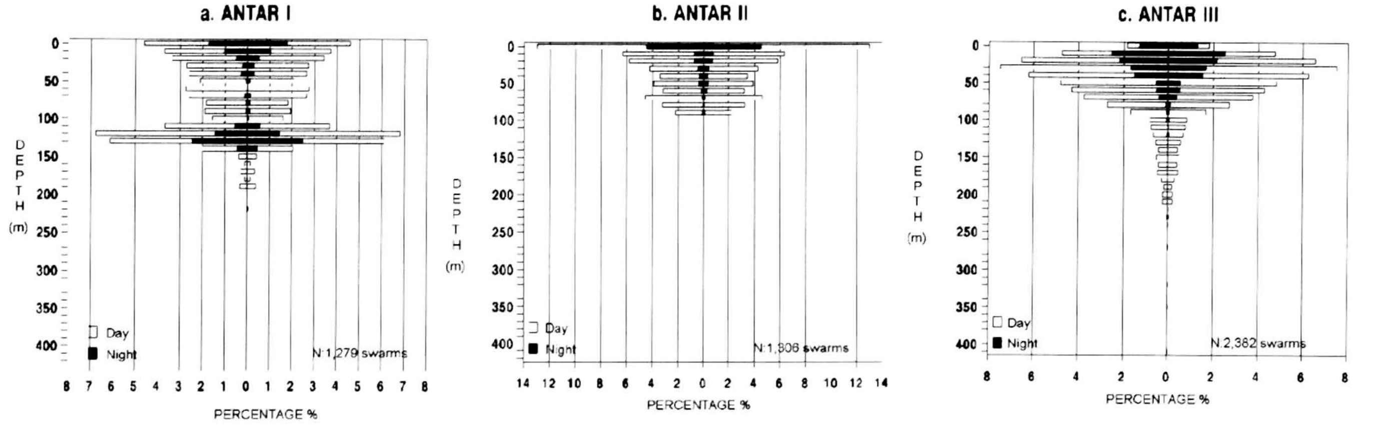

Fig. 5. Vertical distribution of swarms.

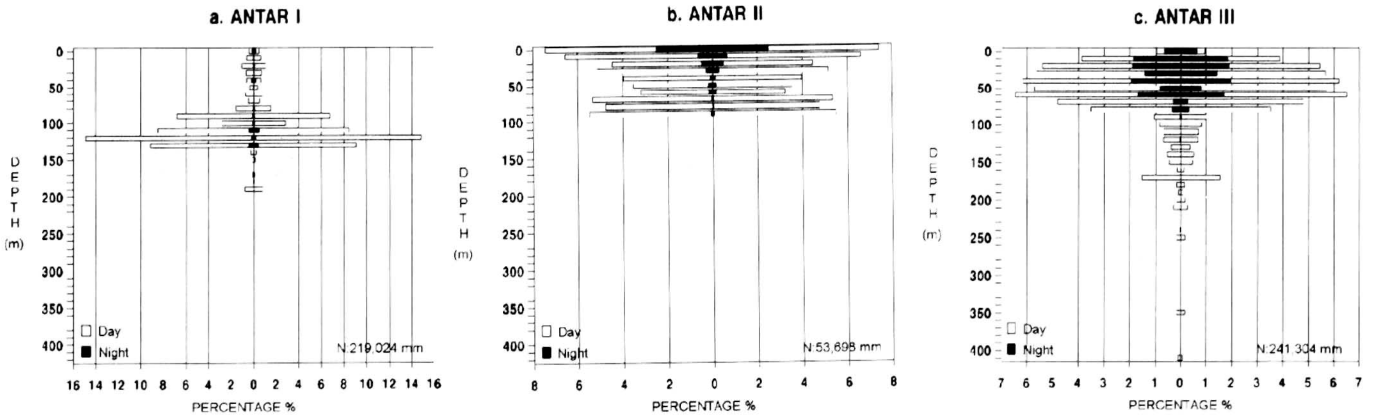

Fig. 6. Vertical echointegrated distribution.

hours, while at night they were in the first 10 m.

Antar III. Swarms detected with the auxiliary 38 kHz sounder were up to 420 m deep in the daylight hours and up to 330 m at night, but it was not possible to prove the identity of such records. During the day, the greater number of swarms was detected around 30 m while in the evening they were around 20 m. The better integration was given during the day around 60 m and at night around 50 m.

Day-night correlation

Through this technique we have obtained average abundance indices through the average of **M** for each hour of the day and the night (Fig. 7).

Antar I. The daytime abundance was greater than the nocturnal, with the highest value occuring between 05 and 06 and the smallest between 23 and 24 hours. The night-to-day ratio (Cn/Cd) was 0.77. Cd attained 831.99 mm and Cn 645.92 mm.

Antar II. The daytime average (Cd) of the distribution was 217.44 mm while the nocturnal average (Cn) was 169.42 mm. The relationship between the daytime and nocturnal abundances (Cn/Cd) was the same as that observed for ANTAR I, namely 0.77. The greatest average value of **M** was 1,126.2 mm between 18 and 19 hours and the least was 6.5 mm between 05 and 06 hours.

Antar III. The distribution was more consistent, according to the ratio (Cn/Cd) which had a value of 0.54 in this case. The greatest abundance (average **M**) was found between 07 and 08 hours (1,410.89 mm) and the least between 05 and 06 hours (50.9 mm). Cd and Cn reached 530.42 mm and 288.57 mm, respectively.

Length frequency

The trawl catches are used firstly for the identification of the echotraces registered by the detection equipment and, secondly, for the collection of krill specimens to determine the size structure of the detected swarms for biological studies. A sub-sample of the total in each trawl catch was measured for

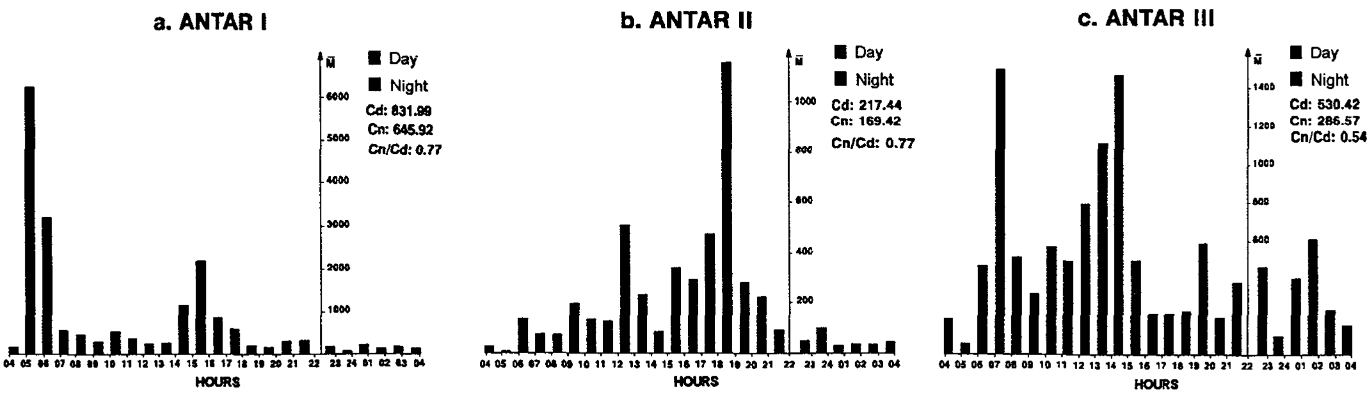

Fig. 7. Day - night correlation.

Table 4. Temperature and salinity maxima and minima observed for krill during compete surveys (Source: Vilchez *et al.* 1988, 1989, 1991)

Expedition (*Antar-*)	*I*	*II*	*III*
Max. temperature (°C)	1.50	1.00	1.50
Min. temperature (°C)	-1.00	-0.50	-0.50
Max. salinity (‰)	34.50	34.25	34.40
Min. salinity (‰)	33.00	33.50	33.50

this purpose.

Antar I. 349 specimens were measured in total from 3 valid trawls obtaining a size range from 25 to 50 mm, with mode at 40 mm and an average of 38.99 mm.

Antar II. 1,138 specimens of the total captured were measured in 9 valid trawl hauls, with the observed range between 16 and 56 mm, with a mode at 25 mm and a mean of 34.12 mm.

Antar III. 1,127 specimens of the total captured were measured in 10 valid trawls with the observed range between 25 and 58 mm, a mode at 48 mm and a mean of 46.71 mm.

Oceanographic conditions and their relationship to krill

Antar I. It was characterized by the calm state of the sea (Beaufort "1"). The presence of swarms was associated with an isothermal between 1.5 and -1,0°C and between isohalines of 33.0 to 34.5‰. The zones in which the highest concentrations were located were between depths of 50 to 150 m associated with an isothermal between 1.0 and -1.0°C and with the salinities of 34.0 to 34.5‰ (Table 4).

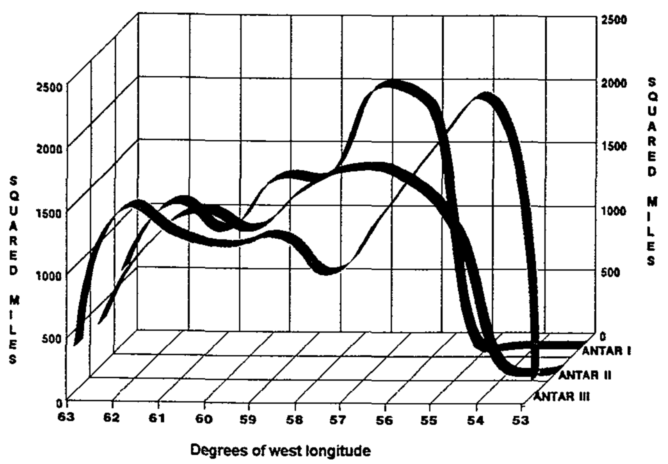

Fig. 8. Distribution area of krill by degrees of longitude (Source: Vilchez *et al.* 1988, 1989, 1991).

Antar II. The prevailing sea state was on the Beaufort scale of "2" to "3". The swarms of krill were associated with an isothermal between -0.5 and 1.0°C and with isohalines of 33.5 to 34.25‰ (Table 4).

Antar III. The predominant sea state was "3" on the Beaufort scale. The krill appeared to be associated with the isothermals of 1.5 and -0.5°C and between isohalines of 34.0 to 34.5‰. The better concentrations (Elephant Island) were down at depths of 30-80 m, associated with isothermals of 1.0 and 0.0°C and with isohalines of 34.2 to 34.4‰ (Table 4).

Biomass by degrees of longitude

Most of the biomass during *Antar I* was between 57° and 58° of west longitude, with 6,510,389 ton, while in *Antar II* it was between 56° and 57° with 2,670,579 ton; for *Antar III* it was between 54° and 55°, with 3,227,540 ton (Fig. 8; Table 5). The positive areas (areas with presence of krill) showed the highest

Table 5. Biomass (ton) and positive area (nm^2) by degrees of longitude (Source: Vilchez *et al.* 1988, 1989, 1991)

Longitude	*Antar I*		*Antar II*		*Antar III*	
(°W)	Biomass	Area	Biomass	Area	Biomass	Area
53-54	-	-	-	-	32,530	118
54-55	-	-	-	-	3,227,540	2,336
55-56	-	-	113,950	1107	705,900	1,924
56-57	5,126,184	1,900	2,670,579	1509	726,770	1,414
57-58	6,510,389	2,045	639,520	1586	523,890	954
58-59	3,203,917	1,338	339,775	1423	522,310	1,244
59-60	760,715	1,318	125,623	1113	726,240	1,168
60-61	445,580	920	387,407	1250	1,224,850	1,248
61-62	684,876	1,127	1,241,125	1013	575,450	1,462
62-63	268,339	598	154,947	361	69,120	370
Total	17,000,000	9246	5,672,924	9362	8,434,600	12,238

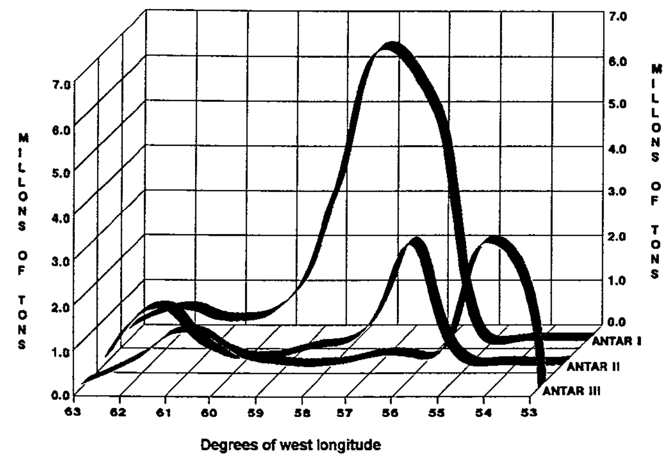

Fig. 9. Total biomass of krill by degrees of longitude (Source: Vilchez *et al.* 1988, 1989, 1991).

values between 54° and 59° of west longitude (Fig. 9; Table 5).

Total biomass and confidence limits

The calculations showed biomasses of, for *Antar I,* 17,000,000 ton (536.05 g m^{-2}) with confidence limits of 29.41%; for *Antar II,* 5,672,924 ton (176.66 g m^{-2}) with confidence limits of 16.66%; and for *Antar III,* 8,434,600 ton (200.93 g m^{-2}) with confidence limits of 12.00%.

Discussion

The horizontal distribution observed for krill during *Antar I, II* and *III* corroborates the observations of other authors, namely that during the southern summer large concentrations of krill are present in the Bransfield Strait and the surroundings of Elephant Island.

Concerning the vertical distribution of the swarms, different distributions obtained between the three ANTAR Surveys. This was not due to any changes in the thermal and haline structure of the water column, since only small fluctuations of the oceanographic parameters were observed between the surveys; such changes would be related to the availability of food between one summer and another. From a general perspective it has not been possible to deduce common behavior standards. However, vertical distributions have been constructed firstly from the observed magnitude of echointegration, and secondly from the count of swarms by depth interval. Comparison of these distributions showed that the small aggregations tend to be in the near-surface layers, while at greater depths there is a smaller number of swarms but they are individually much larger in size.

The day-night comparison showed there was substantial aggregation both by day and by night. The timing of the peak indices (corresponding to the densest aggregations) was different in the nocturnal and daytime periods, which does not lead to any obvious conclusions about the behavior pattern. However, it is informative to note that the ratio Cn/Cd was similar during both *Antar I* and *Antar II* (0.77), suggesting that as regards the day-night aggregation there is a consistent index that might be validated through further research. In *Antar III,* however, Cn/Cd attained the lower value of 0.54, but this was observed over a considerably greater area

The magnitude of the calibration constant did not show any relationship to the size composition of the krill population. The abundances of the krill differed between the three ANTAR Surveys, however these fluctuations do not explain the differences between the three values "C" obtained. Thus it is clear that the magnitude of "C" depended not only on the reflective properties of the krill, but crucially on electronic aspects as well, a problem which should be overcome by using more modern methodologies based on calibrations by standard target and the application of appropriate equations for the Target Strength.

The value of "C" was a function of the concentration density of krill in a known space or volume, one which can be considered as the simulation of a real situation. This one value of "C" is adopted for the biomass calculations in all areas of the survey. This is a statement of the currently employed method, however, it is not appropriate to use a unique constant; the variability of the size structure of the krill population is changing in space, as it is for any other species, therefore it is necessary to use, in any event, so many constants as the numbers of age groups that might be distinguished within the population. To do this it would be necessary to undertake more intensive biological sampling.

Notwithstanding the previous considerations, the acoustical investigations of krill, and particularly those accomplished during the ANTAR Surveys, are valuable in providing knowledge of the distribution and indices of abundance of krill which help in monitoring of their evolution in time, and that outcome is most important for the scientific management of fisheries.

The displacement of the positive areas (areas with presence of krill) does not seem to follow any standard pattern. There is a certain trend towards higher values between 54 and 57 degrees of west longitude (the zone between King George and Elephant Islands), but it can be appreciated clearly that the abundance, at least in the Bransfield Strait, is always important, beyond the differences in the levels of abundance observed between the ANTAR Surveys.

The central biomass estimates differ among themselves and with some equivalent estimates made by other researchers. In all these cases, it is considered that krill are not present in the first eight meters of depth. This introduces an uncertainty factor with respect to the biomass estimates, and therefore they should be considered only as indices of abundance and not as absolute estimates.

Conclusion

The oceanographic parameters do not seem to have any effect on the horizontal distribution of krill, expressed as the density by area over the whole water column. There should be more in-depth studies concerning the availability of food in relation to the presence of krill.

The vertical distribution showed clearly that, at least for *Antar I*, the small swarms were concentrated in the near-surface layers while the most dense were located at greater depths.

The best distribution zones were around Elephant Island, the King George Islands and the Deception-Trinidad Islands.

Biomass estimates must be considered as indices of abundance and not as absolute estimates.

The day-night correlation values suggested the existence of a proportional correlation related to the nocturnal dispersion.

Acknowledgements

I would like to thank Mr. David MacLennan and Dr. Kenneth Foote for their helpful comments and language editing; Mrs. Patricia Dermer who corrected the manuscript; and Mr. Jairo Calderón for his elaboration of the graphics. They all made important contributions to improve this modest work.

References

Bazigos G. 1976. The design of fisheries statistical surveys-Inland waters.

Johannesson K. and Vilchez R. 1981. Application and some results of echo-integration methods in monitoring Peruvian anchovy resources. FAO-NORAD.

Vilchez R., Gonzales A., and Casanova H. 1988. Resultados del estudio de la distribución, comportamiento y abundancia del krill en el Estrecho de Bransfield. *In*: *Informe de la Primera Expedición Científica Peruana a la Antártida*. CONAAN.

Vilchez R., Gonzales A., Castillo R., and Casanova H. 1989. Resultados del estudio de la abundancia, distribución y comportamiento del krill mediante técnicas hidroacústicas en el Estrecho de Bransfield. *In*: *Informe de la Segunda Expedición Científica Peruana a la Antártida*. CONAAN.

Vilchez R., Gonzales A., Ganoza F. , Salazar C. and Gutiérrez M. 1991. Distribución, comportamiento y biomasa del krill en el Estrecho de Bransfield. *In*: *Informe de la Tercera Expedición Científica Peruana a la Antártida*. CONAAN. pp. 189-220.

Received 20 September 1997
Accepted 23 December 1997