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# Distribution and abundance of krill — *Euphausia superba* Dana — at the ice edge zone between Elephant Island and the South Orkney Islands in the season 1988/89

ABSTRACT: In the investigated area the overall abundance of krill was small and was increasing with the distance from ice. However, with the data available, it was not possible to decide whether this increase was related to the ice border or was a part of a larger scale phenomenon. The depth distributions as well as the mean values of krill depth were similar to those of open water both in this study and reported in literature.

Key words: krill, ice zone.

## Introduction

First reports on dense concentrations of krill, mainly larval and adolescent stages, collected near the ice edge and under the pack ice are those of Discovery expeditions (Fraser 1937, Marr 1962, Mackintosh 1972, 1973). Polish data also note presence of *Euphausia superba* in the Antarctic subfast ice community (Rakusa-Suszczewski 1972). Later in the eighties several authors have reported higher densities of small krill at the ice edge than in the open waters: Stępień

(1982) in the Weddell Sea, Nast (1982) and Guzman (1983) in the Antarctic Peninsula region and Miller (1985) in the Prydz Bay. Thus, in a different geographical areas the same phenomenon was observed. This suggests that there is a relationship between ice border and adolescent krill. According to Hamner *et al.* (1989) the ice itself provides a site for the development of social behaviour and transition from isolated individuals to swarms. Although the association of ice and krill has long been a subject of discussions, there are only a few works which deal specifically with this problem (Mackintosh 1972, Daly and Macaulay 1988, Marschall 1988, Bergstrom *et al.* 1989, Cuzin-Roudy and Schalk 1989, Hamner *et al.* 1989, Siegel *et al.* 1990).

In 1983 a special program called AMERIEZ (Antarctic Marine Ecosystem Research at the Ice Edge Zone) was designed to examine the influence of the spatial and seasonal dynamics of the ice edge zone on the abundance and distribution of organisms. Daly and Macaulay (1988) described results of these expeditions related to krill. From their studies it seems that the ice border did not affect the vertical distribution and abundance of *E. superba*, unlike the other trophic levels from bacteria to sea birds which showed an increase in abundance at the ice edge (Ainley and Sullivan 1984). In 1986 the Winter Weddell Sea Project was carried out, which confirmed an earlier hypothesis of Guzman (1983), Boyd C.M., Heyraud and Boyd C.N. (1984) and the observations of Spiridonov, Gruzov and Puškin (1985) that during winter sea ice provides both shelter and food for krill (Marschall 1988). In the season 1988/89 two expeditions to the Antarctic were directed to the sea-ice zone. The first, of the r/v „Polarstern", with the international team on board, investigated the Antarctic ecosystem in macroscale and the second, Polish expedition of the r/v „Profesor Siedlecki", which investigated the ice edge zone in mesoscale.

This paper presents the results of an acoustic survey performed by „Profesor Siedlecki" to determine abundance and distributions of krill at the ice edge.

## Materials and methods

### Study area

Measurements were performed during austral summer (25 December 1988 - 17 January 1989) between Elephant Island and the South Orkney Islands along the 2340 Nm of a zig-zag track. The maximum distance from the ice border was about 30 Nm and there were 3 oceanographical stations on each straight line segment (Fig. 1). From oceanographical data collected during this expedition (Tokarczyk *et al.* 1991) it was clear that there were waters from two main sources in the investigated area: the Bellingshausen Sea water flowing through the Drake Passage and Bransfield Strait, and water from the Weddell Sea. They mixed in the zone of the Weddell-Scotia Confluence, which was situated near 53.5°W. The Weddell Sea water was found in the central and eastern parts of the investigated area. There was a thin layer of warm water of low salinity near the
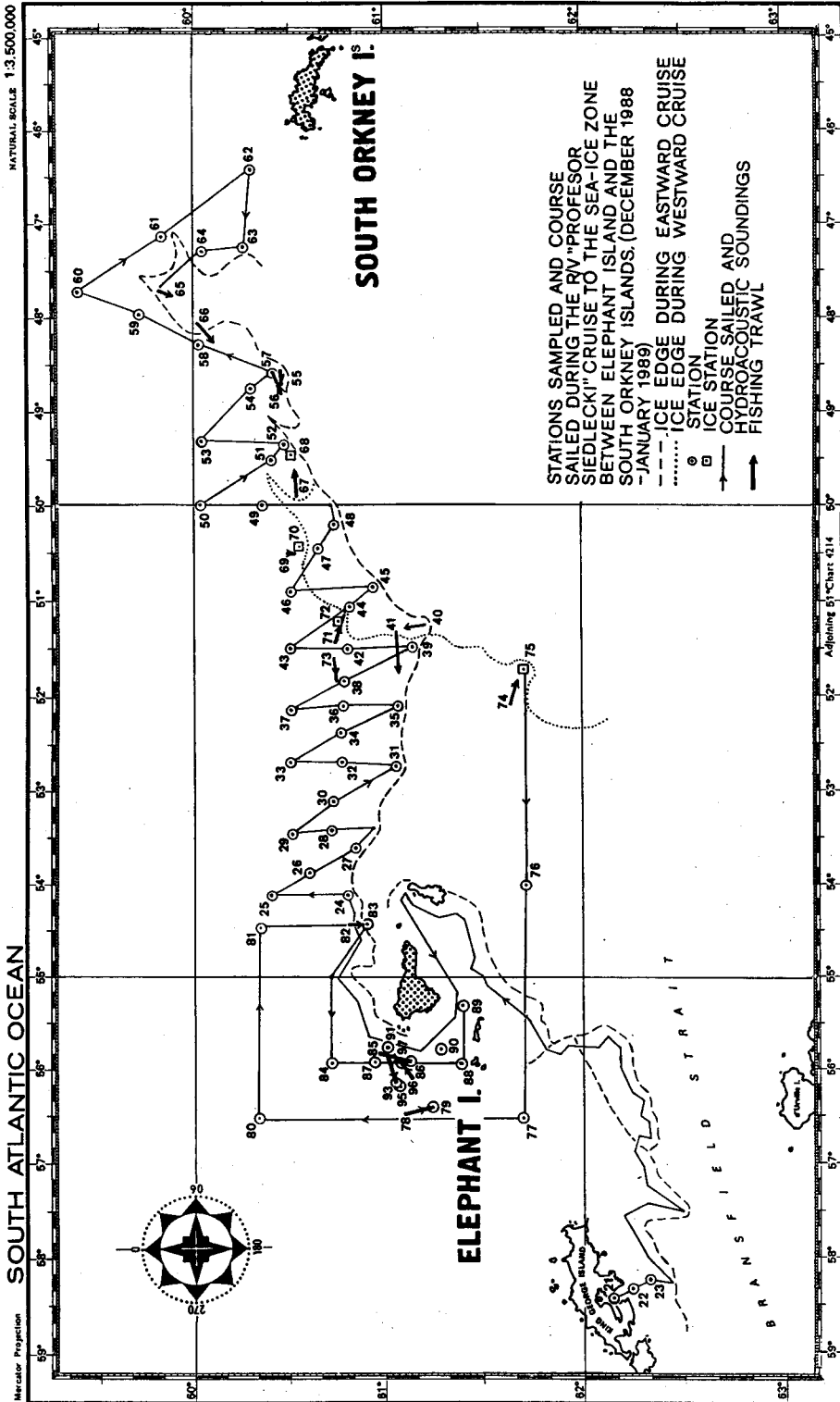
Fig. 1. Map of the investigated area and positions of oceanographical stations

South Orkney Islands, due to the influence of melting ice. Only in the central part of the investigated area, from 53.5°W to 49°W, there was relatively homogeneous water with low temperature, high salinity level and high silicate concentration. Only the data from this central area, from station 28 to 53, were chosen for examining the ice influence on krill distribution in order to avoid the influence of such factors as mixing of different water masses, proximity of islands etc.

Data gathering system

The system of hardware and software solutions chosen for the gathering of hydroacoustic data enabled the real-time sampling of envelope of analog echo signals and storage of numerical data on the system hard disk.

The following basic assumptions were taken into consideration:

— Simrad EK 120 echo-sounder system was a source of analog echo signal and synchronized pulses;

— the vertical resolution of ping should equal 10 cm (typical time of conversion equals 60 microseconds);

— the depth range should be from 0 to 100 m (starting from the face of transducer);

— samples of each ping should be completed with the additional information on ping number, exact time, geographical coordinates, vessel course and speed;

— the system is based on an IBM PC XT compatible microcomputer equipped with the 40 MB hard disk, and standard A/D converter card.

Because of the need of synchronization between sampling and the echo signal as well as the real-time nature of the process, both, the hardware and software should support undisturbed operation under control of synchronization pulses sent by EK-120 sounder.

The operational system was as follows:

— the process of sampling was started by the trigger pulse sent from EK-120 sounder;

— the samples for each ping were stored in the form of one record in real-time;

— one record of samples with supplementary information was stored on the hard disk during the idle time between succeeding pings.

1. Hardware design

The IBM PC computer system does not support the external hardware interrupts which were unavoidable to achieve full synchronization with the trigger pulses. A specialized internal card was designed to solve the problem — an Intel 8255 PIO chip was applied for hardware interrupt (INT3) generation; the same chip was used for transfer of the vessel log pulses. The following input signals were connected to the computer system:

— the envelope of analog echo signal      — to A/D converter card,
— trigger pulse signal                                  — to custom-made 8255 card,
— log pulses                                                — to custom-made 8255 card.
All the input signals were over-voltage protected.

## 2. Software design

The software for data collecting system was divided into two parts: the main part written in Pascal (Turbo 4.0 dialect) for data storage and pre-processing, and the sampling part written in 8086 assembler fol real-time sampling.

The assembler procedure, written as an interrupt handler, was installed by the main program during the initiation phase. The procedure supported the service of INT3 interrupt signal as well as coordination and timing of the analog echo signal sampling. The record of 1024 numerical volume related to the echo signal level was obtained as a result of a single procedure call.

The main program performed the following functions:
— organization of data files stored on hard disk,
— interface with the user (additional data input and updating),
— pre-processing of sample records and their evaluation,
— storing of sample records with the additional information on the hard disk device.

The program enabled the real-time storing of data, displaying of sample data in a semi-graphic form and on-line updating of evaluation criteria and parameters. To minimalize the hard disk access time all the files were written down to the disk using an optimized, sequential method. The free disk space was displayed permanently to enable the operator to perform compression and archivization of files during stops at the stations.

Apart from the computer system a standard hydroacoustical survey was performed with EK-120 echosounder and analog data integrator recorded every nautical mile together with date, time and position.

## Data analysis

Detailed analysis of the acoustic data followed the methods recommended by BIOMASS (1986). Measurements of the returned voltage were made for every 0.1 m, than squared and summed into 10 m depth intervals and averaged for every 1 Nm.

For biomass estimates the target strength expression was used in a form:
$$TS = -95.7 + 19.9 \log L$$
and the weight of krill was calculated from Rakusa-Suszczewski (1981) formula:
$$W = 0.018 L^{3.3831}$$

where:    L  — length of krill in mm
               W — wet weight of krill in mg
               TS— target strength of krill in dB.

## Results and discussion

Depth distributions

To study the influence of the ice border on krill distribution the investigated area was divided into two subareas:

1. ice edge area, which was formed by the segments from the near ice stations to the middle ones;

2. open sea area, composed of segments of the track from the middle stations to the most external ones (Fig. 1).

Depth distributions of krill aggregated in swarms were analysed separately for two distinguished subareas. The cumulative percentage curves are shown in Fig. 2. For near ice area the 10% of biomass was above 28 m, 50% above 48 m and 90% above 68 m. For the open sea area these values were a bit less — 22 m, 35 m and 60 m, accordingly. These results are close to those received by Daly and Macaulay (1988), who for all the stations received 10% of the biomass above 10 m, the 50% level at 34 m and 90% level at 67 m. The mean depth of krill swarms was 42.31 m for the near ice area and 39.27 m for open water, which also did not differ significantly from values received by Daly and Macaulay (1988) — 47.3 and 35.7 m, respectively.
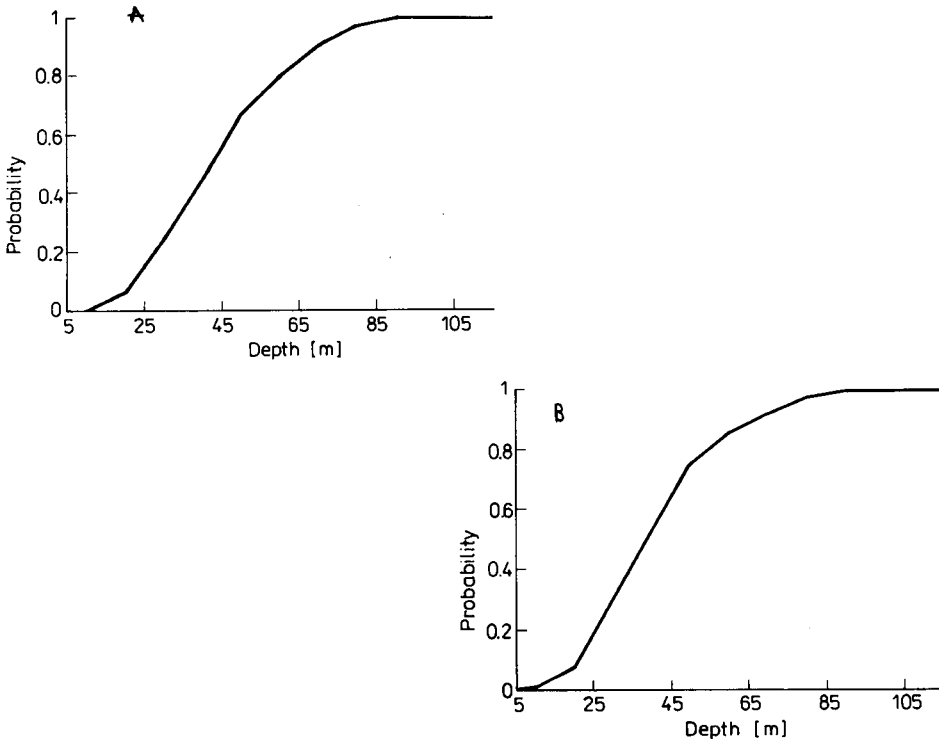


Fig. 2. Cumulative percentage curves of krill biomass depth distributions: A — for the near ice area; B — for the open sea area

Histograms of depth distributions in 10 m layers averaged from the data available for the same periods of time in two subareas are presented in Fig. 3. Only minor differences are present. Generally, it seems that the mean depth of krill is more or less the same in the whole Antarctic.
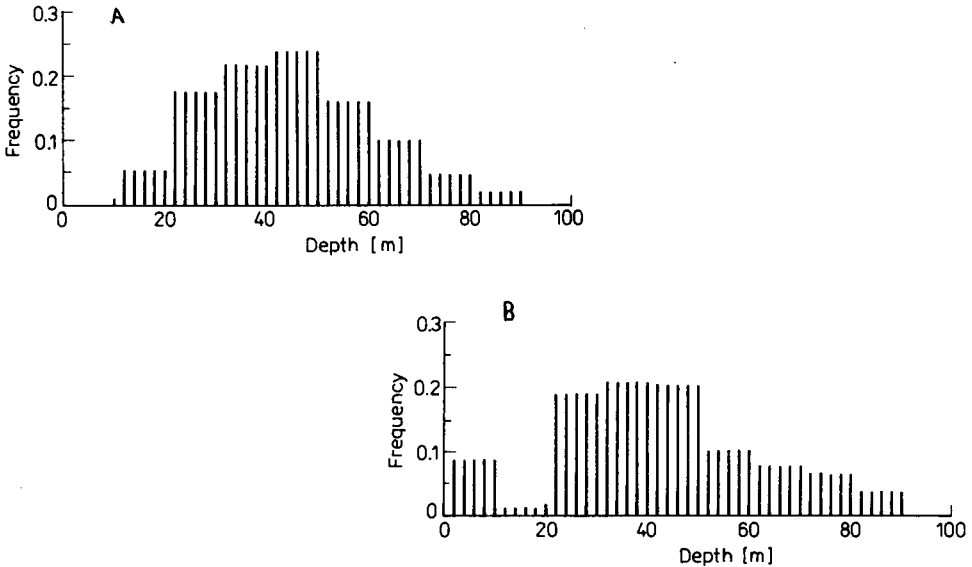


Fig. 3. Histograms of krill depth distributions in 10 m layers: A — for the near ice area; B — for the open sea area

Abundance

The spatial distribution of krill and its abundance along the track of the ship were highly variable. All types of aggregations were present (Kalinowski and Witek 1985) large, dense concentrations, called superswarm — in the region of the Elephant Island; compact swarms, tens to hundreds meters long — mainly close to the South Orkneys; irregular forms, loosely defined layers and small swarms most frequently in the near ice area. The mean density of krill estimated for two distinguished subareas was 6.54 $t/Nm^2$ (1.9 $g/m^2$) and 7.33 $t/Nm^2$ (2.1 $g/m^2$), accordingly. The highest values were observed near station 46, where the maximal surface density recalculated from 1 Nm readings accounted to 66 $t/Nm^2$ (19.49 $g/m^2$). This was clearly related to a dramatical change in the bottom depth, which went up from 3000 m to 300 m within few miles. Also between stations 43–44 high concentrations were observed with the highest density of 36 $t/Nm^2$ (10.5 $g/m^2$). The mean density of krill in the near ice area (mean 6.5 $t/Nm^2$, range 0.5–36.0 $t/Nm^2$) was about one third of the biomass near Elephant Island (mean density 20.15 $t/Nm^2$, range 0.5–195.0 $t/Nm^2$) and one fourth of that near the South Orkney Islands (27.3 $t/Nm^2$, range 0.5–389.5$t/Nm^2$).
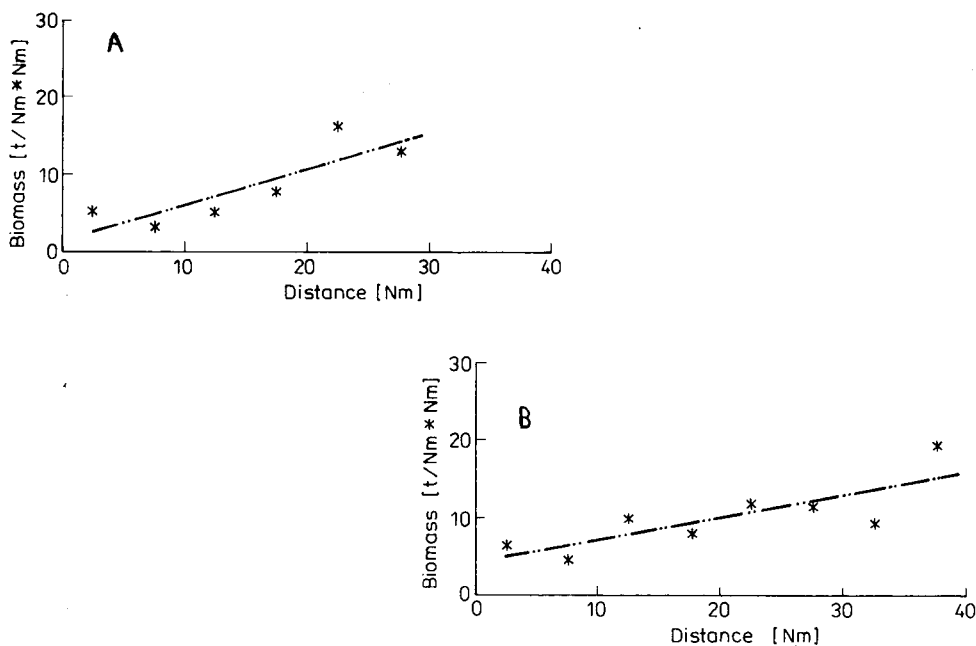
Fig. 4. Regression curves for changes of krill abundance with distance from the ice edge:
A — meridional segments of the ship track; B — sloped segments of the ship track

It was also lower than the values observed by Daly and Macaulay (1988 — 4.8–343.0 t/Nm$^2$). To examine the influence of the ice border on krill distribution the changes of abundance with distance from ice were investigated. The values of volume backscattering strength (means for five nautical miles) were regressed against the distance along all the straight segments of the track from the ice edge to open water. For all the segments the regression lines showed clear trends of increment of the abundance with the distance. For the meridional segments (see Fig. 1) mean linear regression had a form: A = 1.46 + 0.46D
where:    A — abundance of krill in t/Nm$^2$,
          D — distance along track in Nm
and for the sloped segments form: A = 4.28 + 0.29 D (fig. 2). For non meridional transects the slope is less steep, as the real distance from ice was smaller in this case. These results are in agreement with Daly and Macaulay (1988), who found that the acoustic biomass distribution generally had the lowest abundances deepest in the pack ice and the highest abundances in open water north of the ice edge. Also Siegel (1988) observed that under usual conditions krill abundance increases after retreat of the pack ice. According to his suggestion krill spends winter under the pack ice and with spring starts to move to open waters. These seasonal migrations of krill may leed to observed trends in abundance distribution as well as to separation of large and small animals (the bigger ones may swim much faster and cover longer distances), which was observed in this

experiment and previously frequently reported (Guzman 1983, Kils 1983, Siegel 1986, 1988). However, migration alone does not explain the increment of biomass as large as follows from the regression line. Another explanation can be that farther north there is more krill brought with currents from the Bellingshausen Sea. This hypothesis is supported by Cluster analysis of size frequency distributions and maturity stage composition of the EPOS results (Siegel *et al.* 1990). One more factor playing the same role is that in free from ice area circulation of water may develop and cause larger concentrations of krill farther from the ice border. The scale of investigations (maximum 30 Nm from the ice border) was too small to decide whether the increase of krill abundance was related to ice edge or was an effect of larger scale patchiness. During the EPOS leg 2 (Bergstrom *et al.* 1989, Cuzin-Roudy and Schalk 1989) a research was conducted along a transect from the Weddell Sea pack ice well into the open waters along the 49°W, thus crossing exactly our area. Unfortunately the echo integrator was not used during this study and acoustic data can not be analysed quantitatively.

Apart from the increase of abundance with the distance from ice an east-west gradient was also apparent with the western side of the survey area having higher average biomass than the eastern side. This east-west gradient was also present in Daly and Macaulay (1988) results.

## Conclusions

The overall biomass of krill at the ice edge zone was low as compared with the other regions (Elephant Island and the South Orkney Islands). It was increasing with the distance from ice, but with the data available it was not possible to decide what was the reason for such horizontal distribution; the ice border itself or other factors (hydrodynamics?). The mean depth distributions of krill were not affected by the presence of ice. However, the diurnal changes of these distributions differed from those for open water (Godlewska and Klusek, 1991).

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## Streszczenie

Przeprowadzono analizę biomasy i rozmieszczenia kryla w rejonie granicy paku lodowego pomiędzy wyspą Elephant i Orkadami Południowymi. Stwierdzono, że biomasa kryla w pobliżu granicy lodowej była niższa niż w rejonach wysp. W miarę oddalania się od lodu biomasa kryla wyraźnie rosła, jednak dostępne dane nie pozwoliły określić, co było przyczyną tego wzrostu — oddziaływanie lodu, czy też czynniki hydrochemiczne. Obecność lodu nie miała wpływu na średnie głębokości występowania kryla, jednak proces migracji kryla przebiegał z mniejszym okresem i amplitudą niż na wodach otwartych.