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Krill migration pattern at the ice edge zone (December 1988 – January 1989)

ABSTRACT: At the ice edge krill undergoes diurnal migrations with the period of 12 hours and amplitude of about 6 meters. The mean depth of krill occurrence is 41 m, shallower then for open waters. In our opinion these migration parameters are characteristic of juvenile adolescent krill dominating at the ice edge.

Key words: krill, migration.

Introduction

From the extensive literature concerning krill depth distributions (Marr 1962, Shevtsov and Makarov 1969, Kalinowski 1978, Arimoto *et al.* 1979, Nast 1979, Everson and Ward 1980, Kalinowski and Witek 1980, 1985, Everson 1983, Tomo 1983, Morris 1985, Godlewska and Klusek 1987, Godlewska 1988, Katsuragawa (unpub.), Klusek and Godlewska 1988) it is clear that diurnal vertical migration of *E.superba* does not follow a simple pattern. Krill swarms are frequently recorded at any depth at the top 200 m of the water column at any time of the day. Marr (1962) found that the concentrations of *E.superba* occurred down to 160 m, but most frequently in the upper 10 m. Shevtsov and Makarov (1969) observed that both at night and during the day the range of occurrence was similar and did not exceed 70 m, but during the day krill concentrated at the water surface. On the basis of numerous data collected from Peter I Island in the Bellingshausen Sea up to the South Sandwich Islands in the Scotia Sea Kalinowski and Witek (1980) concluded that in the most of areas krill comes close to the surface at night and descends deeper during the day (down to 250 m). The only exception was the South Georgia region, where an opposite pattern was observed (Kalinowski 1978, Everson 1983). Many factors may account for observed distributional variability — abundance and distribution of food, physiological, optical, hydrological and other environmental conditions, which role is known at present. According to Pavlov (1974) a diurnal cycle of movements of krill aggregations was closely related to its feeding cycle. Loeb and Shulenberger (1987) found that at night krill occurred primarily near the top of the seasonal thermocline, and concluded that various changes in krill depth distributions may be related to environmental changes and not necessarily reflect migratory habits. Several authors have considered light conditions as triggering vertical movements of krill (Kalinowski and Witek 1985, Katsuragawa (unpub.), Arimoto *et al.* 1979). The works cited here were based on limited amount of data and a relatively narrow range of analyzed factors, so the results are often contradictory and do not allow to draw general conclusions. Thus the role of different factors in krill migratory pattern still is not fully understood.

We would like to add some new results concerning the sea ice zone, which have not been reported in literature so far, to the existing data on krill migrations. Due to the interdisciplinary nature of the program and a limited time for acoustic and net measurements these data are not complete. By comparing these data with our previous results we have tried to find factors having a significant effect on the parameters of krill migrations such as mean depth, range of migrations and periodicity (Godlewska and Klusek 1987, Godlewska 1988, Klusek and Godlewska 1988).

Materials and methods

The data were collected during the cruise of r/v „Profesor Siedlecki" to the Antarctic in December 1988 and January 1989 from the ice edge between Elephant Island and the South Orkney Islands (Fig. 1). The distance from ice was 30 Nm and we assumed that the influence of ice, the border of which is very dynamic, spreads out at least up to this distance. It follows, from oceanographical data collected during this cruise (Tokarczyk *et al.* 1991), that the investigated area had rather complex hydrochemical structure. Only in the central part between 53°30′W and 49°W (i.e. between stations 28 and 53) there was a relatively homogenous water of the Weddell Sea origin. The data from only this area were taken for the investigation of krill distributions in order to avoid the influence of such factors as mixing of different water masses, the influence of the shelf (near islands) etc. Also biologically the krill from the central area was different from that living around Elephant and the South Orkney Islands (Kittel and Siciński 1991). It had a mean length of 31.9 mm and juvenile individuals dominated with a share of 50%, while at Elephant and the South Orkney

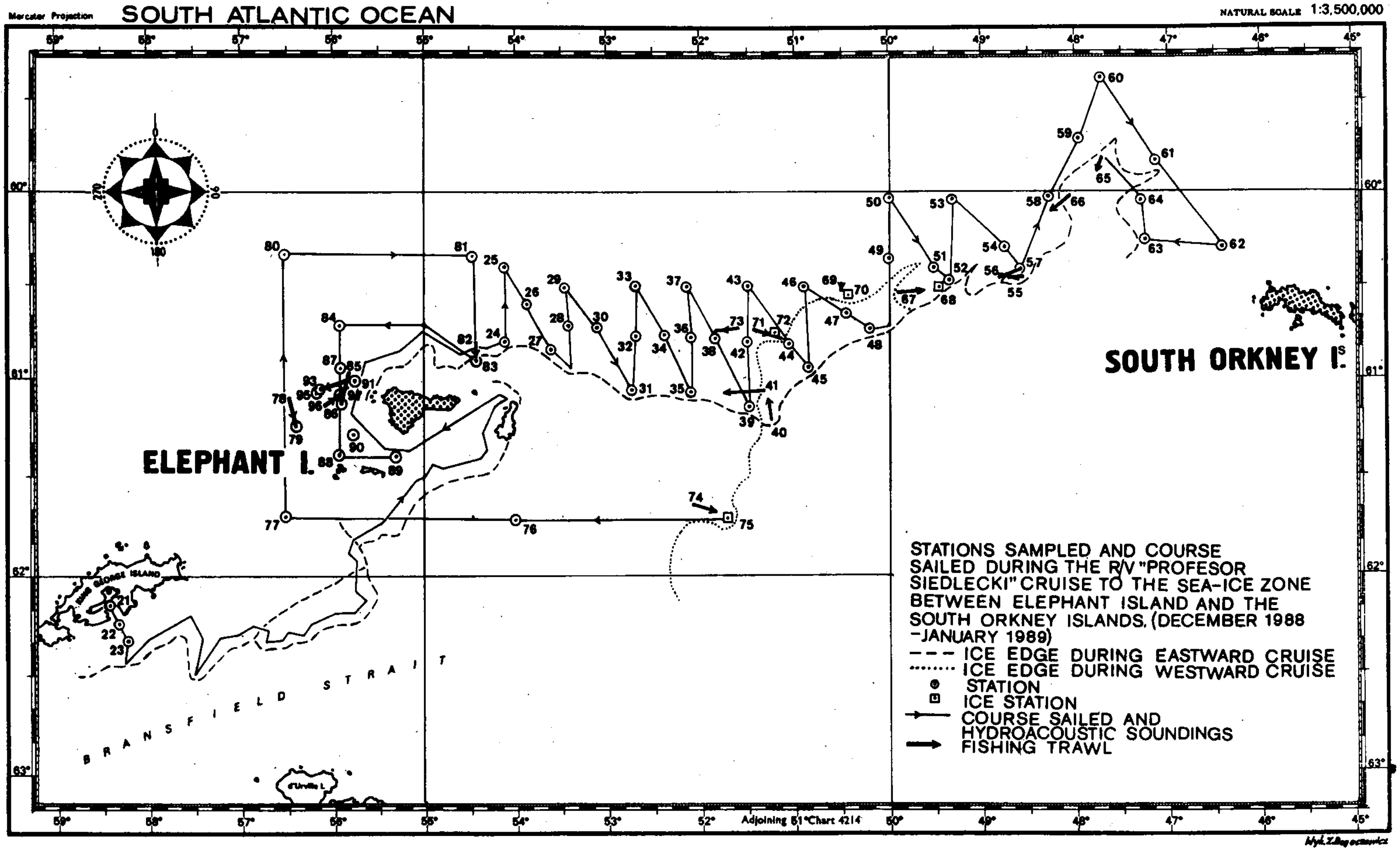

Fig. 1. Map of area under investigation and position of oceanographic stations

Islands krill was substantially larger (with the means of 40.3 and 41.2, respectively) and more mature.

Hydroacoustic measurements were performed in a 24 hour watch system, with a Simrad EK-120 echosounder and an analog echointegrator. Simultaneously krill swarms were recorded on IBM/XT computer to allow for a bigger space resolution of the swarm structure — 10 cm vertically. The method of analysis was the same as in Godlewska and Klusek (1987). Data set was divided for 12, two-hour intervals, in which the depth of the biomass mass center was determined. Next the time dependence was approximated by the function:

$$H(t) = A + B\cos(2\pi t/T_1 + \phi_1) + C\cos(2\pi t/T_2 + \phi_2) \quad (1)$$

where:

A — is the mean depth of krill occurrence,
B — is amplitude of migrations with period T_1 = 24 hours,
C — is amplitude of migrations with period T_2 = 12 hours,
ϕ_1 and ϕ_2 are the phases, determining the time when migration starts.

All the parameters of the equation were calculated using least squares method (Marquard 1963).

From the echogram paper the mean depth of each swarm was found (as the upper plus lower limit of krill aggregation divided by two) and the mean value for each time interval calculated. These data were also approximated by function (1) using least squares method.

Table 1

Diurnal changes of krill distribution

time	number of swarms	mean swarm depth	mean biomass depth	number of pings	number of miles	SV dB
0–2	62	48.27	37.63	2181	63	-47.5
2–4	37	45.11	48.49	4394	65	-48.8
4–6	76	67.09	43.83	2449	67	-49.3
6–8	52	44.80	39.03	3341	33	-51.7
8–10	76	43.12	32.24	3192	30	-52.3
10–12	44	40.50	41.43	3909	27	-54.2
12–14	15	57.47	44.14	4707	33	-52.6
14–16	30	49.20	49.16	2762	37	-53.9
16–18	26	65.96	45.11	8660	56	-49.0
18–20	11	61.00	41.08	5546	53	-52.3
20–22	23	57.30	40.38	7141	22	-52.8
22–24	14	32.50	33.06	5757	52	-50.8

Results

To allow for an analysis of diurnal changes the data set was divided for 12 two-hour intervals and for each of them the following parameters were found: the number of miles passed, the number of pings recorded (non zero), the number of swarms, the mean depth of krill biomass and of swarms as well as the mean volume backscattering strength Sv (Tab. 1). Due to the long time spent on oceanographical and ice stations the coverage of all time intervals was not the same, with about a half nautical miles sailed during a day as compared to those sailed at night. To avoid distortion of the results by this fact, the depth distributions were analyzed in each time interval separately, assuming the biomass of krill in a given interval to be 100%. Histograms of krill biomass distribution in 10 m layers and 2 hour time intervals are presented in Fig. 2, while analogical histograms of krill swarms distribution in Fig. 3.

The krill migrations were also described in two ways: as diurnal changes of a biomass mass center and of a mean depth of swarms (Figs 4 and 5). The migration parameters for these two cases were as follows:

$$A=41.3,\quad B=-2.1,\quad C=5.8,\quad \phi_1=0.78,\quad \phi_2=-0.32,\quad T_1=24,\quad T_2=12;$$
$$A=51.0,\quad B=-4.7,\quad C=9.5,\quad \phi_1=0.18,\quad \phi_2=\ 1.14,\quad T_1=24,\quad T_2=12.$$

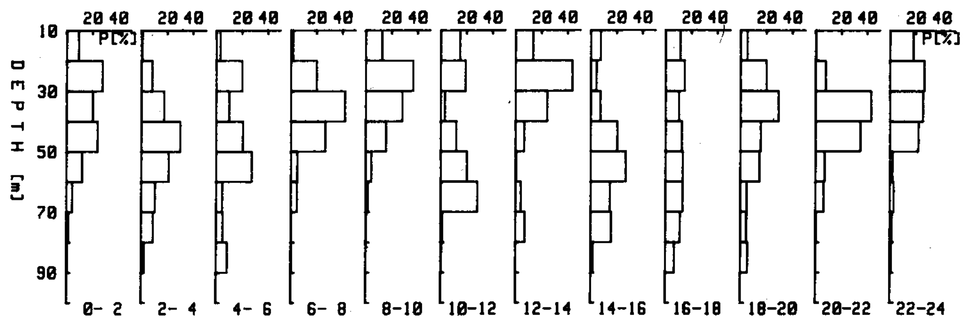

Fig. 2. Histograms of krill biomass depth distribution in 10 m layers and 2 hour time intervals (the krill biomass in each time interval is considered as 100%)

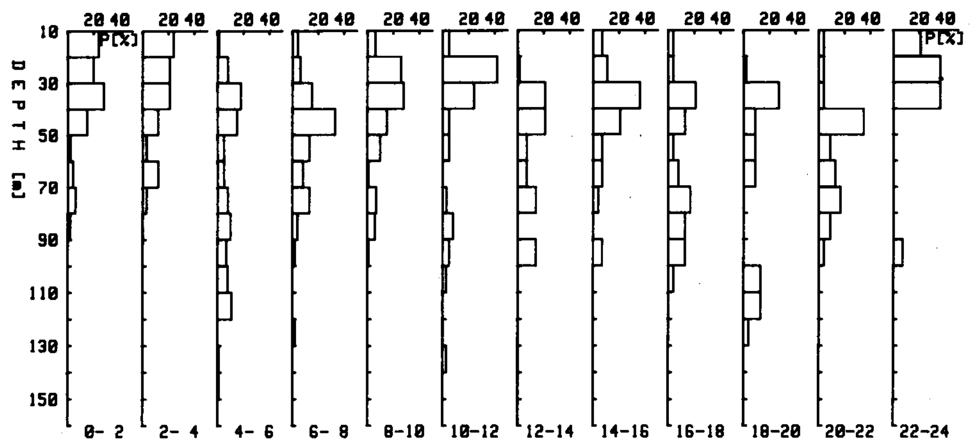

Fig. 3. Histograms of krill swarms mean depth distribution in 10 m layers and 2 hour time intervals (the number of krill swarms in each time interval is considered as 100%)

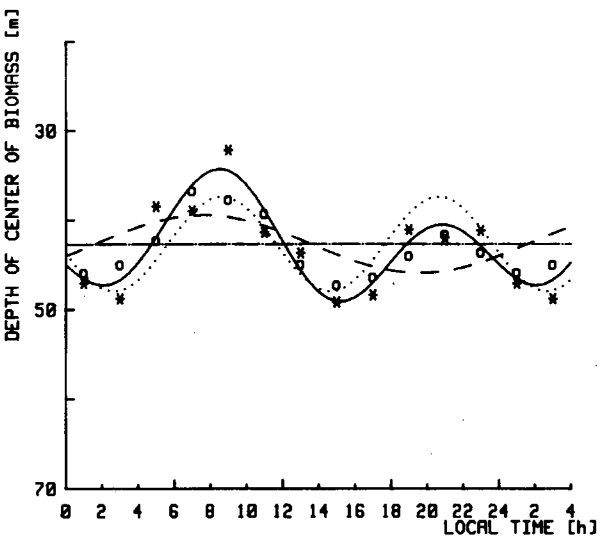

Fig. 4. Diurnal changes of the krill biomass mass center. The migration parameters are following: mean depth A = 41.3 m, amplitude of migrations with 24 hour period B = 2.1 m, amplitude of migrations with 12 hour period C = 5.8 m, start of migrations — 3 A.M. and just before noon for 24 and 12 hour period accordingly

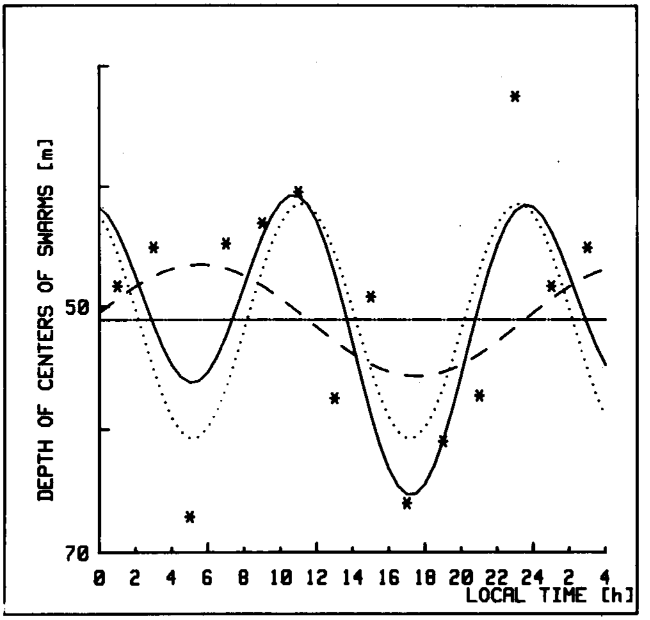

Fig. 5. Diurnal changes of the mean depth of krill swarms. The migration parameters are following: amplitude of migrations with 24 hour period B = 4.7 m, amplitude of migrations with 12 hour period C = 9.5 m; start of migrations is about 1 A.M. for 24 hour period and 2 A.M. for 12 hour period

Discussion

From Figures 2 and 3 it is clear that depth distributions of krill at the ice edge zone change very little with time. The greatest amount of krill all the time occupies depths of 30–40 m, with the maximum moving to the top 20 m during night (22–2 hour) and descending to 50 m at noon time (12–14 h). Although single aggregations were observed down to 150 m (Fig. 3), the biomass of krill below 80 m did not exceed 5%. The mean depth of krill biomass was 41 m while the mean depth of swarms was 51 m. These values differ from those of Daly and Macaulay (1988), who for ice-edge/open water stations received the mean swarm depth equal 35.7 m and the mean depth of krill biomass equal 67.0 m. If we compare these values with those for open sea (Kalinowski and Witek 1985, Loeb and Shulenberg 1987, Katsuragawa unpub.), it seems that the ice edge does not influence depth distributions of krill, at least the mean depths of krill occurrences are within the same range. However, it should be noted that in the near ice area we never met krill below 150 m, while in other areas it was observed occasionally down to 250 m or even deeper (Guzman 1983, Kalinowski and Witek 1985). This might be result of dominance of juvenile and adolescent stages at the ice edge (Marr 1962, Mackintosh 1972, Daly and Macaulay 1988, Kittel and Siciński 1991). The juvenile and adolescent stages amplitude of migrations is expected to be smaller than that for adults (Everson 1983).

From Figs. 4 and 5 we can see, that the period of 12 hours is clearly dominating in krill migration pattern. Taking into account krill population structure (juvenes – 50%, immature – 30% and mature – 20% (Kittel and Siciński 1991), this is also in agreement with Everson's hypothesis that small animals migrate with a shorter period than the larger ones. The amplitude of migrations calculated from the mean depth of swarms is about two times larger than that calculated from the biomass mass center, for both periods.

In order to analyze which factors influence krill migration parameters we collected all available data in Table 2. From these data only very preliminary conclusions can be drawn. However, it is evident that the size of krill is one of the parameters on which migration depends. For the smallest animals both, the mean depth and the amplitude are also the smallest, while for adults they are substantially larger. The period of migrations is also related to size. The juvenes

Table 2

Parameters of krill migrations and the environment

region	time	A	B	C	dominant stage	L (mm)	Chl a (mg/m^3)
ice zone	Dec./Jan.	41	2.1	5.8	juvenes	32	0.2 – 0.4
SIBEX	Dec./Jan.	53	13.8	–	immature	36	1.59
Bransf./El.	Oct./Nov.	62	19.5	4.6	adults	44	0.59
Elephant	January	73	0.5	3.6	adults	43	0.1 – 0.5

and immature krill have a strong component of 12 h, while mature animals have usually 24 h period.

There are two possible patterns of migration in relation to food availability. Either there is a little phytoplankton and krill migrates in order to increase the probability of encountering food (than amplitude of migrations should be negatively correlated with chlorophyll concentration) or migration is caused by sinking of repleted animals (Pavlov 1974, Everson 1983) and than amplitude of migrations would be positively correlated with chlorophyll concentrations. The BIOMASS III data seem to favour the first pattern – during spring krill was present mainly in a form of compact, very well packed foraging swarms (Kalinowski 1978, Godlewska and Klusek 1987). Concentrations of chlorophyll were very low (Lipski 1985, Lipski and Zieliński 1988) and the amplitude of migrations was the largest from all the values observed (Klusek and Godlewska 1988). Around Elephant Island the diurnal migrations are small (Tab. 2) and often reported as absent (Macaulay, English and Mathisen 1984, Loeb and Shulenberg 1987) although phytoplankton concentrations are always low (probably because of a high grazing pressure of krill, whose large concentrations are observed in this area). The only explanation for this we can see at present is that in this area the water dynamics is more responsible for krill distributional pattern than its behaviour. Krill around Elephant Island is distributed mainly in a thick irregular layers extending from the top to about 100 m, so called super-swarms. The compact swarms, so characteristic for other areas are hardly observed.

During SIBEX the concentrations of chlorophyll were the highest (Lipski 1985) and abundance of krill very small (Kalinowski, Godlewska and Klusek 1985). There was a clear migration pattern, with rather high amplitude (Godlewska and Klusek 1987), which would favour the second pattern of migration. However, it should be remembered that the SIBEX results were collected from a large area of different hydrological regions and population structures. Because of small amounts of krill during that season, it was impossible to split the data between clearly differing regimes like the Bransfield Strait, the Drake Passage or Elephant Island. Therefore the result should be taken with caution. However, it seems quite probable that both patterns in krill migrations are present. If only the second one was correct, than there would be no explanation for krill migrations at low concentrations of chlorophyll, which were very strong during spring and well expressed at the ice edge.

Conclusions

At the ice edge krill showed a clear diurnal migration pattern. It was closest to the surface at night (18–2 h) and before noon (6–10 h) and deepest just after noon (12–14 h). Krill were migrating mainly with 12 hour period, although a weak component of 24 hour was also present (Figs. 4 and 5). The amplitude of migrations, as compared to that of open water was rather small and the mean depth of krill distribution shallower. We think, that these small values of all the migration parameters were related to juvenile and adolescent krill, clearly dominating at the ice edge (50% – juvenes).

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Streszczenie

Przeprowadzono analizę migracji kryla w oparciu o dane hydroakustyczne zebrane w czasie rejsu r/v „Profesor Siedlecki" do Antarktyki w okresie 26.12.1988 – 17.01.1989. Terenem badań była strefa przylodowa pomiędzy wyspą Elephant i Orkadami Południowymi.

Stwierdzono, że kryl w strefie przylodowej wykazuje migracje o okresie 12 godzin i amplitudzie około 6 m. Dla wód otwartego morza okres migracji wynosi 24 godziny i amplitudy są z reguły większe. Również średnie zanurzenie kryla w strefie przylodowej h = 41 m jest mniejsze niż dla wód otwartych. Autorzy uważają, że te małe wartości parametrów migracji są wynikiem dominacji w strefie przylodowej osobników młodocianych.