POLISH POLAR RESEARCH	9	2–3	349—356	1988

Zygmunt KLUSEK [1]) and Małgorzata GODLEWSKA [2])

[1]) Department of Physics,
Institute of Oceanology,
Polish Academy of Sciences,
Powstańców Warszawy 55, 81-718 Sopot, POLAND

[2]) Department of Polar Research,
Institute of Ecology,
Polish Academy of Sciences,
Dziekanów Leśny, 05-092 Łomianki, POLAND

Depth distribution and day-night migrations of krill (BIOMASS III, October—November 1986, January 1987)

ABSTRACT: On the basis of hydroacoustic observations it is shown that migrations of krill during spring are stronger than during summer. Migrations of krill are described by the function: $H(t) = A + B\cos((2\pi t/T + \varphi) + C\cos(2\pi t/T + \varphi)$, where: H is depth of the mass center of krill biomass, A — mean depth of krill occurrence, B — amplitude of migrations with period $T_1 = 24$ h, C — amplitude of migrations with period $T_2 = 12$ h, φ_1, φ_2 — phases of migration process with $T_1 = 24$ and $T_2 = 12$ hours. Parameters of the equation are the following:
spring — A = 62.2 m, B = 19.5 m, C = 4.6 m, $\varphi_1 = 0.1$ h, $\varphi_2 = 0.15$ h;
summer — A = 75.8 m, B = 0.5 m, C = 3.6 m, $\varphi_1 = 1.8$ h, $\varphi_2 = 6.4$ h.

Key words: Antarctica, krill, migrations, BIOMASS III.

1. Introduction

Although krill vertical migrations have been reported and described many times (Marr 1962; Ševcov and Makarov 1969; Kalinowski 1978; Arimoto et al. 1979; Nast 1979; Kalinowski and Witek 1980, 1985; Everson 1982, 1983; Tomo 1983; Godlewska and Klusek 1987; Godlewska 1988) the basic questions: why and how krill migrates are still to be answered. Existing literature data are related to limited areas and short time periods and they show the migration process at random. Kalinowski and Witek (1985), who collected large observation materials from 18 regions of the Antarctic have described qualitatively the vertical distribution of krill. The only general conclusion, which can be drawn from their data is that krill migrates up to the surface at night and descends to greater depths during the day (everywhere but in the region of South Georgia). Data on seasonal changes of migration process are completely lacking in the literature. The present paper tries to fulfill this gap by analysing data from the same region for two seasons: spring (October/November 1986) and summer (January 1987). The results presented here are a continuation of the investigations performed during SIBEX 1983/84 and presented in a paper of Godlewska and Klusek (1987). In both papers the migration process has been described by such parameters as the mean depth of krill biomass, amplitude and phase of the process, which permit to clasify easily and to compare the data.

2. Methods and materials

Krill migration analysis was carried out on the basis of hydroacoustic data collected during BIOMASS III (October/November 1986, January 1987) in the Bransfield Strait and the region of Elephant Island by the r/v "Profesor Siedlecki". The signal of the envelope from the SIMRAD echosounder EK-120 (frequency 120 kHz) was registered on a 4-channel tape recorder Bruel Kjaer 7003. Two channels (with different amplification to expand the dynamics of the recorder) were used to record the signal, the other two were used for the pulse trigger and the mile marker. Following the field experiment the signal was digitized and analysed on the minicomputer IBM/PC.

To describe migration pattern the depth of the mass center of biomass distribution for every two-hour interval was calculated separately for spring and summer according to the formula:

$$H(t) = \int_{H_{min}}^{H_{max}} Sv(z\, dz / \int_{H_{min}}^{H_{max}} Sv(z)\, dz$$

where: $H(t)$ — depth of the biomass mass center,
H_{min}, H_{max} — minimal and maximal depth of krill occurrence,
$S_v(z)$ — volume backscattering sound coefficient, which is pro portional to amount of krill in 1 m^3.

Changes of H(t) with time were approximated by a single periodical function, as in Godlewska and Klusek (1987):

$$H(t) = A + B\cos(2\pi t/T + \varphi)$$

where: A — mean depth of mass center of biomass,
B — amplitude of migrations,

T — period of migrations,
φ — phase of migrations, i.e. the time between midnight and start of migrations.

The parameters of the equation were calculated by the method of nonlinear regression (Marquardt 1963).

3. Results and discussion

The depth diistributions in 10 m layers for spring and summer are presented in Fig. 1. It is clear from the picture that the depths of krill occurrences were lower in spring than in summer. From echogram observations, fishery practice and data of BIOMASS-SIBEX expedition it follows that migrations of krill have a period of 24 hour. So in the first approximation, we used the function:

$$H^1(t) = A + B\cos(2\pi t/24 + \varphi).$$

However the matching was not very good. Because in the work of Pavlov (1974) as well as in SIBEX data (Godlewska and Klusek 1987) 12 hour period was also suggested, as a second step we used the function with two periods 24 and 12 hours:

$$H^2(t) = A + B\cos(2\pi t/24 + \varphi_1) + C\cos(2\pi t/12 + \varphi_2).$$

Results for spring and summer are presented in Figs. 2 and 3. Beside the curve described by the last formula, which gives the best matching, the 24 and 12 hour components and the mean value are also shown. The depth of the mass center of biomass was calculated twice, as weighed (H_w) and unweighed (H_n) mean. Both values together with number of swarms are shown in Tables 1 and 2. Although H_w and H_n have a slightly different statistical meaning, they differ only slightly and the time dependence is nearly identical. It follows from Figs. 2 and 3, that during spring krill is distributed shallower than during summer ($H_{spring} = 62$ m, $H_{summer} = 76$ m). This can be caused by two reasons: smaller amount of light in spring than in summer and larger amount of adolescent krill, which feeds intensively in surface layer. During summer the amplitude of migrations is smaller than in spring. We think that these seasonal differences in the migration process are due to seasonal changes in the population structure. In the region of Elephant Island during spring (October/November 1986) we observed 8% juvenes, 70% subadults and 22% adults, while during summer (January 1987) the population structure was following: juvenes 1.5%, subadults 33% and adults 65.5% (Kittel, pers. comm.). It seems that juvenes and subadults migrate more intensively than adults, probably because of their greater food

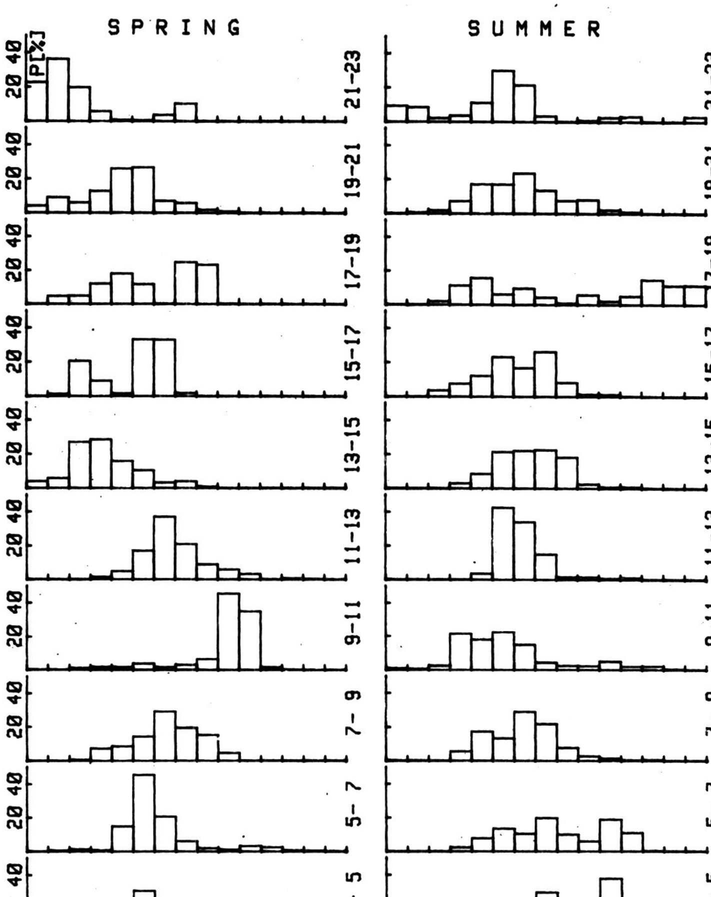

Fig. 1. Vertical distribution of krill biomass in 10 m layers during spring and summer (BIOMASS III, October—November 1986, January 1987). The biomass registered during each two-hour interval is 100%

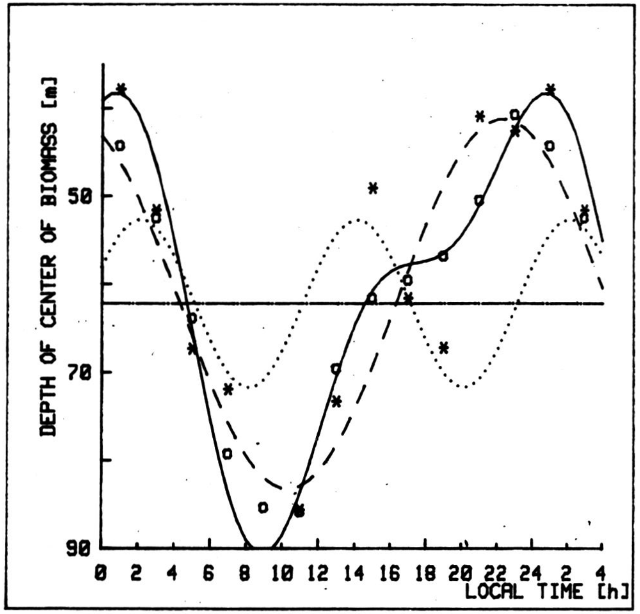

Fig. 2. Time dependence of the depth of mass center of krill biomass during spring (BIOMASS III. October/November 1986). Theoretical curve (continuous line) is described by the function: $\bar{H}(t) = A + B\cos(2\pi t/T_1 + \varphi_1) + C\cos(2\pi t/T_2 + \varphi_2)$, where $A = 62.2$ m, $B = 19.5$ m, $C = 4.6$ m, $T_1 = 24$ h, $\varphi_1 = 0.1$ h, $T_2 = 12$ h, $\varphi_2 = 0.15$ h. Dashed line is $T = 24$ h component, dotted line is $T = 12$ h component;
* — the experimental points, mean for two-hour intervals,
○ — consecutive mean, i.e.: $H(t_n) = [H(t_{n-1}) + H(t_n) + H(t_{n+1})]/3$

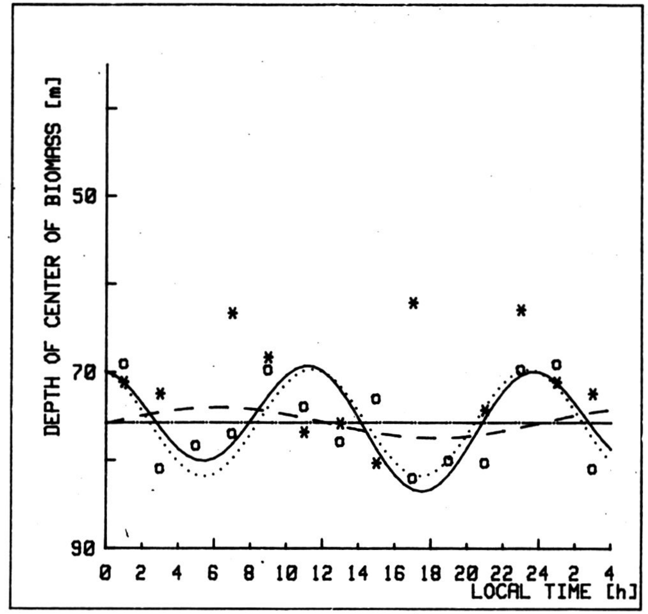

Fig. 3. Time dependence of the depth of mass center of krill biomass during summer (BIOMASS III, January 1987). Theoretical curve (continuous line) is described by the function: $\bar{H}(t) = A + B\cos(2\pi t/T_1 + \varphi_1) + C\cos(2\pi t/T_2 + \varphi_2)$, where $A = 75.8$ m, $B = 0.5$ m, $C = 3.6$ m, $T_1 = 24$ h, $\varphi_1 = 11.8$ h, $T_2 = 12$ h, $\varphi_2 = 6.4$ h. Dashed line is $T = 24$ h component, dotted line is $T = 12$ h component;
* — the experimental points, mean for two-hour intervals, ○ — consecutive mean, i.e.:

$$\bar{H}(t_n) = [H(t_{n-1}) + H(t_n) + H(t_{n+1})]/3$$

Table 1
Diurnal changes of weighed (H_w) and unweighed (H_n) depths of the center of krill biomass during sprint (BIOMAS III, October — November 1986)

Time (h)	H_n (m)	H_w (m)	number of swarms
0— 2	38.6	37.8	14
2— 4	50.5	51.6	23
4— 6	68.7	67.3	34
6— 8	71.0	71.9	33
8—10	94.3	97.7	31
10—12	83.5	85.6	41
12—14	70.1	73.3	28
14—16	48.2	49.1	12
16—18	63.2	61.6	8
18—20	67.1	67.2	8
20—22	43.8	40.9	32
22—24	29.1	42.6	23

Table 2
Diurnal changes of weighed (H_w) and unweighed (H_n) depths of the center of krill biomass during summer (BIOMASS III, January 1987)

Time (h)	H_n (m)	H_w (m)	number of swarms
0— 2	69.5	71.1	27
2— 4	78.3	72.4	6
4— 6	99.0	98.5	11
6— 8	62.7	63.3	12
8—10	66.4	68.3	34
10—12	73.6	76.8	17
12—14	76.2	75.8	6
14—16	82.8	80.3	12
16—18	61.8	62.1	73
18—20	98.0	102.9	61
20—22	73.5	74.3	45
22—24	60.7	62.9	22

demands, both for growth and respiration (Rakusa-Suszczewski and Godlewska 1984), related to unit weight. However the amount of data is not sufficient to state this definitely. As suggested by Everson and Ward (1980) one can expect larger amplitudes for adult krill and smaller for juvenes, but this opinion has not been proved by field observations of krill populations. Our result contradicts also the conclusions of Nast (1979) who examined migration of larval and adult krill based on net hauls made during a time station (February 1976) positioned south of Elephant Island, and found that vertical distribution of juvenile krill resembles that of adults, with the same amplitude of migration of about 70 m. Shulenberger, Wormuth and Loeb (1984), who performed a detailed net-sampling of a large krill swarm near

Elephant Island in March/April 1981 did not observe a diel vertical migration neither of adults nor of larvae. It is clear, that the diurnal vertical migration of krill does not follow a simple pattern and there is a need for further investigations to resolve this problem.

This work was supported by the Polish Academy of Sciences within the C.P.B.P.03.03. Project.

4. References

Arimoto T., K. Matuda, E., Homada and K. Kanda 1979. Diel vertical migration of krill swarm in the Antarctic Ocean. — Trans. Tokyo Univ. Fish., 3: 93—96.

Everson I. 1982. Diurnal variations in mean volume backscattering strength of an Antarctic krill (*Euphasia superba*) patch. — J. Plankton Res., 4: 155—162.

Everson I. 1983. Variation in vertical distribution and density of krill swarms in the vicinity of South Georgia. — Mem. Natl Inst. Polar Res., (Spec. Issue), 27: 84—92.

Everson I. and P. Ward, 1980. Aspects of Scotia Sea zooplankton. — Biol. J. Linn. Soc., 14: 93—101.

Godlewska M. and Z. Klusek. 1987. Vertical Distribution and Diurnal Migrations of Krill —*Euphausia superba* Dana — from Hydroacoustic Observations, December 1983/January 1984. — Polar Biol., 8: 17—22.

Godlewska M. 1988. Migracje kryla — Euphausia superba Dana — XV Sympozjum Polarne, Wrocław 19—21 V; 328—335.

Kalinowski J. 1978. Vertical migration of krill in the region of South Georgia, February—March 1976. — Pol. Arch. Hydrobiol., 25: 573—583.

Kalinowski J. and Z. Witek. 1980. Diurnal vertical distributions of krill aggregations in the West Antarctic. — Pol. Polar Res., 1: 127—146.

Kalinowski J. and Z. Witek. 1985 Elementy biologii, formy grupowego występowania kryli — Studia i materiały MIR, B, 52: 162 pp.

Marquardt D. 1963. An algorythm for least squares estimation of nonlinear parameter. — J. Soc. Ind. Apl. Mat., 11: 131—136.

Marr J. W. S. 1962. The natural history and geography of Antarctic krill (*Euphausia superba*). — Discovery Rep., 32: 433—464.

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: 103—118.

Pavlov V. J. 1974. O charaktere svjazi meždu pitaniem i nekotorymi osobennostjami povedenija *Euphausia superba* Dana. — Tr. Vses. Naučno-Issled. Inst. Rybn. Choz. Okeanogr. (VNIRO). 99: 104—116.

Rakusa-Suszczewski S. and M. Godlewska. 1984. Energy flow through krill aggregations in Drake Passage and Bransfield Strait. — J. Crust. Biol., 4 (Spec. No 1): 198—205.

Sevcov V. V. and P. P. Makarov. 1969. K biologii antarktičeskogo krylja. — Tr. Vses. Naučno-Issled. Inst. Rybn. Choz. Okeanogr. (VNIRO), 66: 177—206.

Shulenberger E., J. H. Wormuth and V. J. Loeb. 1984. A large swarm of *Euphausia superba*: overview of patch structure and composition. — J. Crust. Biol., 4 (Spec. No 1): 75—95.

Tomo P. 1983. Study on the diurnal migration of *Euphausia superba* and the formation of schools. — Ber. Polarforsch., 4: 191—195.

Received March 20, 1988
Revised and accepted April 25. 1988

5. Streszczenie

Na podstawie obserwacji akustycznych stwierdzono, że w okresie wiosny wędrówki pionowe kryla odbywają się bardziej intensywnie niż latem. Występują także różnice w głębokości zalegania skupień; wiosną średnia głębokość wynosiła 62 m, latem 76 m.

Migracje dobowe kryla opisano funkcją teoretyczną w postaci: $H^2(t) = A + B\cos(2\pi t/24 + \varphi_1) + C\cos(2\pi t/12 + \varphi_2)$, gdzie H — głębokość środka ciężkości biomasy kryla, A — średnia głębokość występowania kryla, B — amplituda migracji z okresem T = 24 godziny, C — amplituda migracji z okresem T = 12 godzin, φ_1 i φ_2 — fazy procesu migracji określające przesunięcie czasu rozpoczęcia wędrówek w stosunku do północy. Parametry równania wyniosły odpowiednio dla okresu wiosennego:

$$A = 62.2 \text{ m}, \; B = 19.5 \text{ m}, \; C = 4.6 \text{ m}, \; \varphi_1 = 0.1 \text{ h}, \; \varphi_2 = 0.15 \text{ h};$$

dla okresu letniego:

$$A = 75.8 \text{ m}, \; B = 0.5 \text{ m}, \; C = 3.6 \text{ m}, \; \varphi_1 = 1.8 \text{ h}, \; \varphi_2 = 6.4 \text{ h}.$$

Sugeruje się, że sezonowe zmiany procesu migracji spowodowane są zmianą struktury populacji kryla.