POLISH POLAR RESEARCH	9	2–3	357—366	1988

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

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

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

The density structure of krill aggregations and their diurnal and seasonal changes (BIOMASS III, October—November 1986 and January 1987)

ABSTRACT: On the basis of acoustically registered cross-sections of krill aggregations, regular, irregular and layer forms were distinguished. Regular forms are most frequently observed during spring and in the day time, while irregular forms are most frequent during summer and night hours. The density histograms made for two hour intervals clearly show the day-night difference, but the seasonal (spring, summer) difference is less pronounced. Mean density of swarm is lowest during the night and reaches a maximum in early morning hours. The mean volume backscattering strength values (S_v) for spring and summer are nearly identical. We suggest that regular forms correspond to foraging swarms and irregular forms to feeding swarms as described by Hamner (1984).

Key words: Antarctica, krill, BIOMASS III.

1. Introduction

Swarming habits belong to the most important features of *E. superba* which enable krill fishery. In spite of this practical aspect and a great interest in krill as a key species of Antarctic ecosystem, we have very little knowledge concerning the nature of krill aggregations, their structure and dynamics. Most informations are available on geometrical parameters of krill swarms, such as length, thickness and density. These parameters can vary within very wide ranges. Thus, horizontal dimensions may vary between few meters and, in the case of superswarms, few kilometers (Marr 1962; Everson 1982, Macaulay, English and Mathisen 1984; Kalinowski and Witek 1985b). The vertical dimensions change from few meters to 250 m, i.e. they can cover the whole range of krill occurrence. In opinion of Hamner (1984) swarms form an infinite variety of shapes but usually are narrow in at least one dimension, so that individuals within the swarm are not far from its edge. Krill density within the swarm also vary from few $g\,m^{-3}$ for a dispersed structure to few $kg\,m^{-3}$ for dense formations (Anon 1984; Macaulay, English and Mathisen 1984; Kalinowski and Witek 1985b; Brinton et al. 1987). Even within the same swarm krill density may differ by few orders of magnitude (Kalinowski and Witek 1985a). The complex structure of the position of an individual within the swarm probably reflects different aspects of social behaviour and the influence of different environmental factors and thus can be the basis for classification of krill swarms. Existing proposals for krill concentrations classification are not satisfactory, they are based either on characterictics difficult to observe or they are too much dependent on the subjective opinion of the investigator (Mauchline, unpubl.; Kalinowski and Witek 1985a). The aim of the present work was to look with the help of the echosounder and a computer analysis into the internal density structure of the swarm and its diurnal and seasonal changes.

2. Methods and materials

Investigations of krill swarms have been carried out within a BIOMASS III program (October—November 1986, January 1987) on two polygons in the region of Weddell-Scotia Confluence (Elephant Island region and Bransfield Strait). The signal of the envelope from the SIMRAD echosounder EK-120 (frequency 120 kHz) was registered on a tape recorder, and afterwards digitized and analyzed on the minicomputer IBM/PC. A swarm was recognized when three subsequent echoes exceeded the detection threshold. For nuch sxurm the followinc ckaracsnrrstics were bmundB

— histogram of krill density distribution within a swarm,
— depth profile of krill density,
— cross-section of a swarm.

On the basis of 613 registered swarms the day-night and seasonal analysis has been performed. Diurnal changes of swarm density were presented as means and as histograms of S_v in two-hour intervals separately for spring and summer. S_v — the volume backscattering strength, is a measure of the amount of sound energy reflected back from 1 m^3 of water. Mean S_v (MVBS) was taken as the standard abundance parameter in BIOMASS program.

3. Results and discussion

All swarms registered during BIOMASS III were divided according to the shape of their cross-section, into regular forms (compact swarms), irregular forms and layers (Figs. 1, 2 and 3). This classification does not differ fundamentally from that of Kalinowski and Witek (1985a), it is only limited to these three types, which are easy to be distinguished on the echo-sounder paper. From seasonal analysis of types of swarms (Tabs. 1 and 2) it can be seen that during spring regular swarms are observed most frequently, while during summer the irregular ones prevail. Among all regular forms 75% occurred in spring time. From the diurnal analysis of echograms it follows that regular forms are mainly observed during the day, between 8.00 and 14.00 of local time (LT), while the irregular forms are most frequent during night time, between 18.00 and 2.00 LT. Among compact swarms there are numerous well distinguishable, with a high, stable density across the whole swarm (horizontally and vertically). In our opinion these swarms correspond to those described by Hamner (1984) as "foraging schools, in which Euphausiids are tightly grouped and precisely oriented". On the other hand irregular forms correspond to Hamner's "feeding schools". In these swarms the shape, the density histogram and the density depth profile are very irregular (Figs. 3 and 4). Seasonal analysis of the types of krill swarms seems to support such a classification. During spring (October—November) food availability is poor and the foraging swarms are numerous.

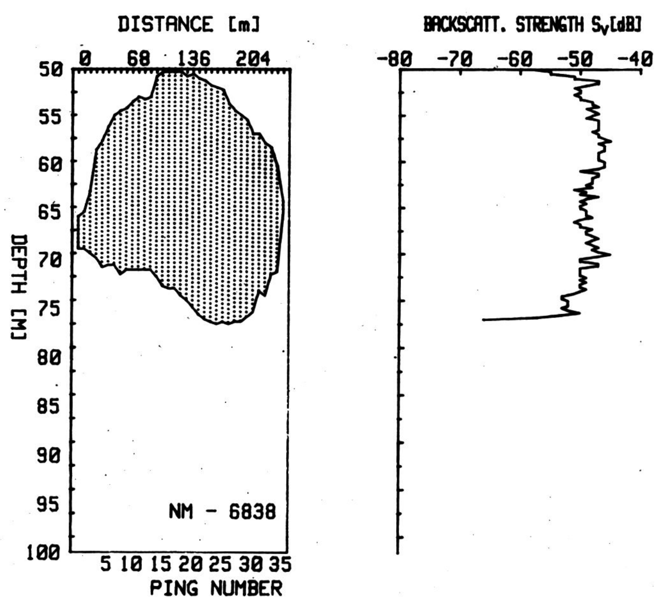

Fig. 1. Cross-section and the vertical distribution of krill density for the regular swarm

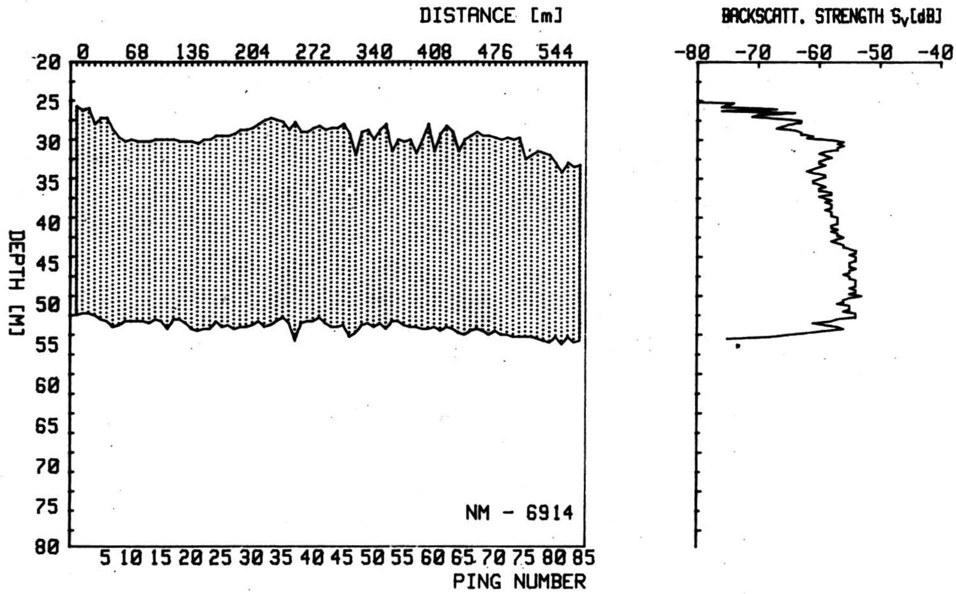

Fig. 2. Cross-section and the vertical distribution of krill density for the layer swarm

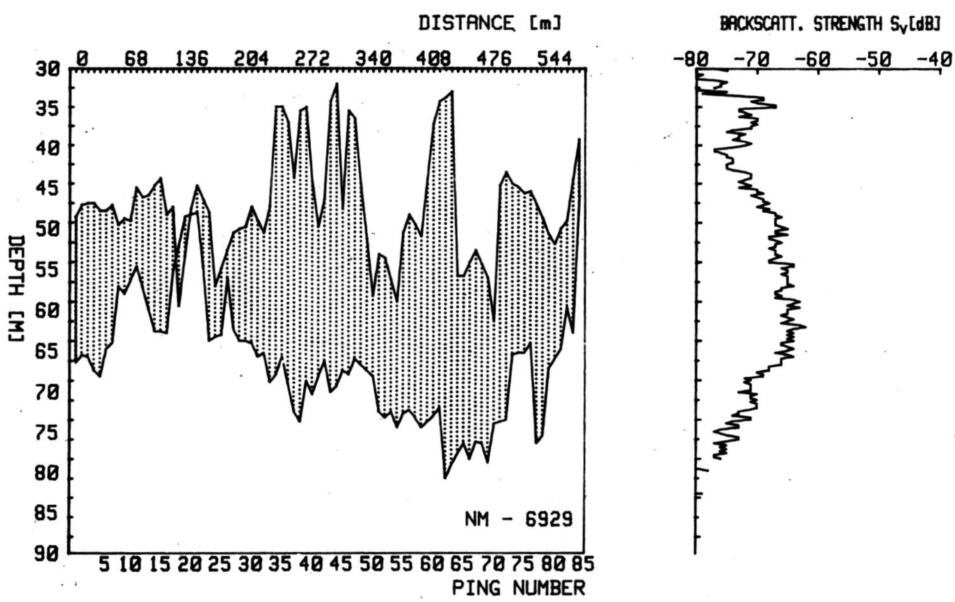

Fig. 3. Cross-section and the vertical distribution of krill density for the irregular swarm

Table 1

Types of swarms during spring and summer

Season	Regular forms	Irregular forms	Layers
Spring	45%	33%	22%
Summer	14%	49%	37%

Table 2

Seasonal changes of the different types of swarm

Type of swarm	Spring	Summer
Regular forms	75%	25%
Irregular forms	38%	62%
Layers	35%	65%

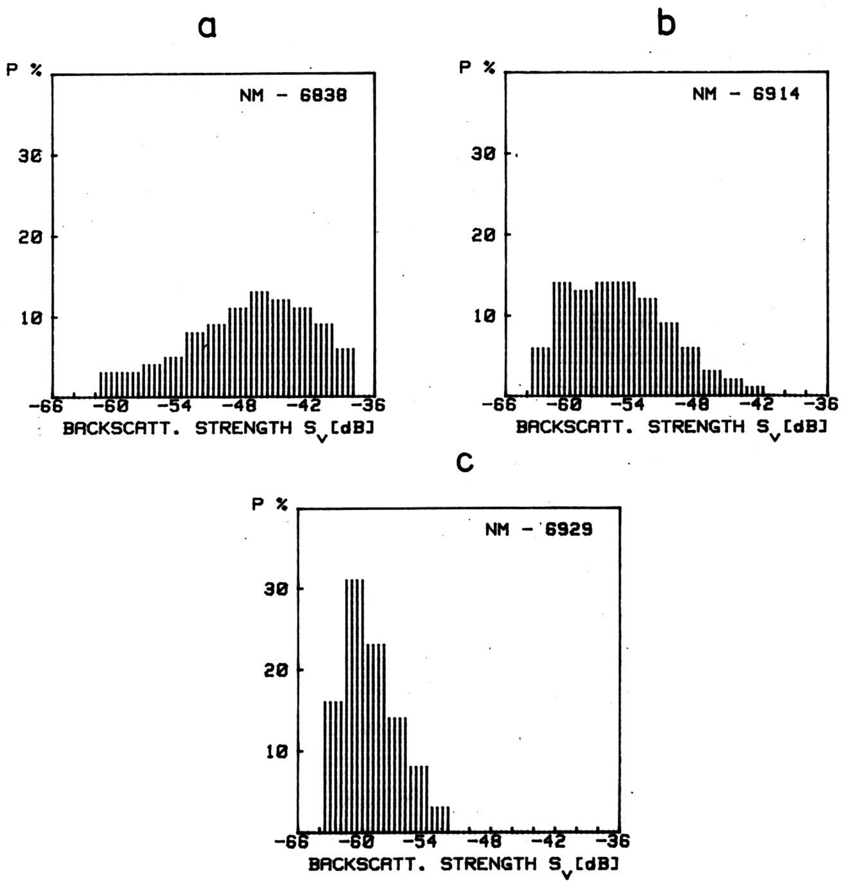

Fig. 4. The krill density histograms
a. for the regular swarm, b. for the layer swarm, c. for the irregular swarm

During summer the situation is opposite. Due to the abundance of food we observed numerous feeding swarms and few foraging swarms. Now let us analyse density structure of swarms (Tab. 3). Diurnal analysis of S_v values (Fig. 5) leads to the conclusion, that krill density is lowest at night and reaches its maximum in early morning hours. This agrees well with the hypothesis that during night krill, which is dispersed in a subsurface layer, feeds intensively and when it is well fed it forms dense concentrations, which begin to descend (Everson and Ward 1980). These swarms reach the largest depths between 8.00 and 10.00 LT and than again ascend to the surface (Godlewska and Klusek 1987; Klusek and Godlewska 1988). The day-night difference in density structure is also evident in density histograms (Fig. 6), beeing more pronounced in spring than in summer. In spite of differences in diurnal changes of S_v values during spring and summer, the mean values for both seasons are nearly the same ($S_v$spring = −49.8 dB, $S_v$summer = −49.2 dB). This result is not unexpected. As we remember $S_v = 10 \log N + TS$ (where N is the number of individuals in 1 m^3 and TS is the target strength of krill). In summer krill body length is considerably larger than in spring but not that much TS, as it dependens on L logarythmically. One of possible sources of variability in SV is that TS depends not only on the length of krill, but also on its orientation. As we stated earlier, during summer most of the swarms are feeding and the animals are probably oriented at some angle to the surface. This leads to the lowering of the target strength. According to Greenlow (1977) the difference in the target strength between an animal situated horizontally and one positioned vertically can be as high as 30 dB. During spring the most numerous are foraging swarms, in which orientation of individuals is probably parallel to the surface, and thus the target strength is maximal. This problem has been first mentioned by Everson (1982) who analysed hydroacoustic data for a large patch of krill and found a difference between day and night values of S_v equal to 8.4 dB. According to this author such a large difference could not be caused by the change of the density itself and he considers the orientation and the multiple scattering as a probable, but, at the present state of our knowledge, impossible to be estimated sources of this effect. The other 7 points is that the mean density values (N) for summer can be lower than for spring due to the fact, that animals within the swarm try to keep constant distance between individuals (Kalinowski and Witek 1985b). When the dimensions of krill grow, their density should be lower. Equality of mean S_v values for swarms observed during spring and summer does not mean equality of biomass. According to Kalinowski (1988) the mean surface density of krill at Elephant Island was in spring 33.7 t nM^{-2} and in summer 48.5 t nM^{-2}. If we take into the account the mean length of krill (L_{spring} = 42.7 mm, L_{summer} = 47 mm; Kittel, pers. comm.) and the

Table 3

Diurnal changes of the volume backscattering strength of swarms

Time hour LT	$S_v$spring dB	$S_v$summer dB	Number of swarms spring	Number of swarms summer	Depth of swarms spring	Depth of swarms summer
0—2	−49.8	−51.2	14	27	37.8	71.1
2—4	−48.2	−46.1	23	6	51.6	72.4
4—6	−48.6	−46.5	34	11	67.3	98.5
6—8	−49.0	−51.2	33	12	71.9	63.3
8—10	−49.0	−48.1	31	34	97.7	68.6
10—12	−49.8	−48.2	41	17	85.6	76.8
12—14	−49.0	−50.7	28	6	73.3	75.8
14—16	−49.4	−48.4	12	12	49.1	80.3
16—18	−50.2	−49.5	8	73	61.6	62.1
18—20	−50.0	−48.2	8	61	67.2	102.9
20—22	−52.0	−49.3	32	45	40.9	74.3
22—24	−52.3	−53.2	23	22	42.6	62.9

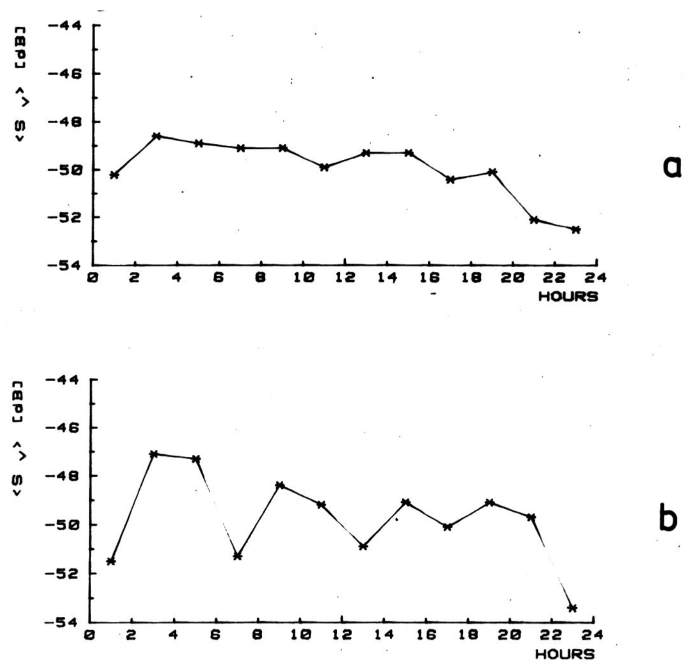

Fig. 5. Diurnal changes of the mean volume backscattering strength for swarm a. for spring (October—November 1986), b. for summer (January 1987)

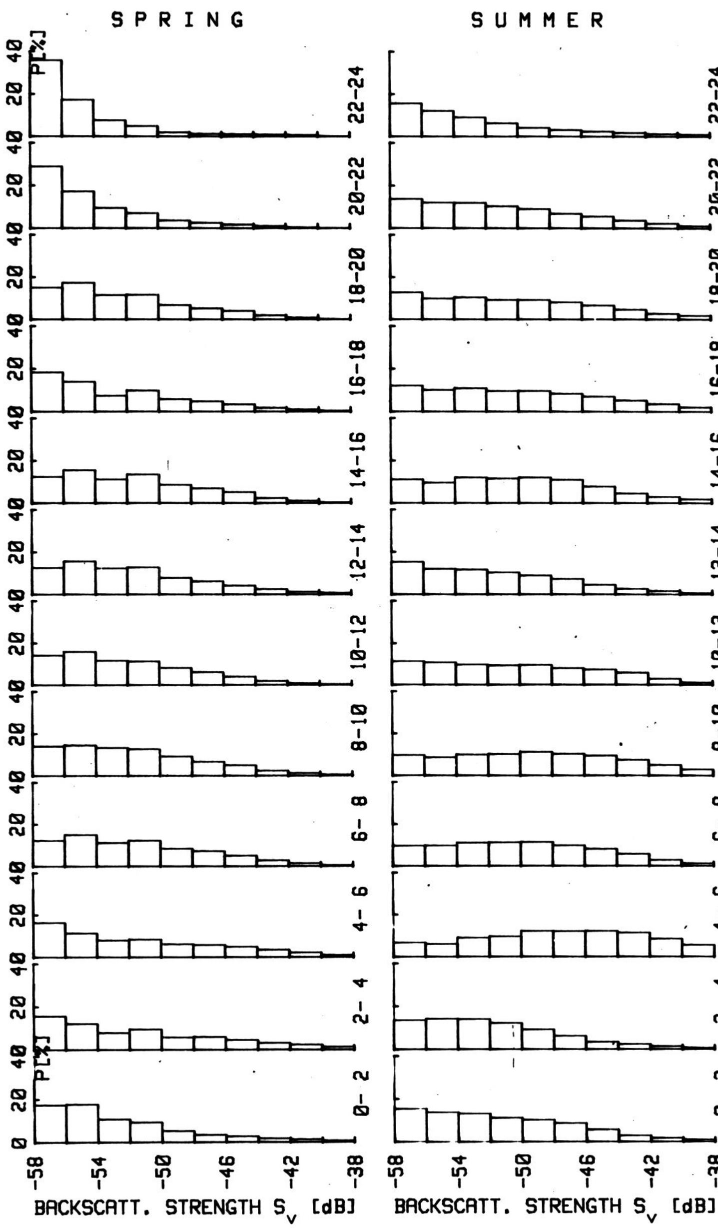

Fig. 6. Diurnal changes of krill density histograms for spring (October—November 1986) and summer (January 1987)

relation between the weight of individual and its body length ($W = 0.0018\ L^{3.3831}$; Jażdżewski et al. 1978) we can easily calculate, that observed growth of krill biomass was due to the growth of individuals.

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

4. References

Anon. 1986. Post-FIBEX Acoustic Workshop, Frankfurt (FRG), 3—14 September 1984, BIOMASS Rep. Ser., 40;

Brinton E., V. J. Loeb, M. C. Macaulay and E. Shulenberger. 1987. Variability of *Euphausia superba* populations near Elephant Island and the South Shetlands: 1981 vs 1984. — Polar Biol., 7: 345—362.

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

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 Hydroacoustical Observations, SIBEX, December 1983 — January 1984. — Polar Biol., 8: 17—22.

Greenlow Ch. F. 1977. Backscattering spectra of preserved zooplankton. — J. Acoust. Soc. Am., 62: 44—52.

Hamner W. M. 1984. Aspects of schooling in *Euphausia superba*. — J. Crust. Biol., 4 (Spec. No 1): 67—74.

Jażdżewski K., J. Dzik, J. Porębski, S. Rakusa-Suszczewski, Z. Witek and N. Wolnomiejski. 1978. Biological and populational studies on krill near South Shetland Islands, Scotia Sea and South Georgia in the summer 1976. — Pol. Arch. Hydrobiol., 25: 607—631.

Kalinowski J. 1988. Biomass variability of krill in the South Shetland Islands region (BIOMASS III, October 1986 — January 1987). — Pol. Polar Res., 9: 327—338.

Kalinowski J. and Z. Witek. 1985a. Scheme for classifying aggregations of Antarctic krill. — BIOMASS handbook, 27: 12 pp.

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

Kanda K., T. Takagi and Y. Seki. 1982. Movement of the larger swarms of Antarctic krill *Euphausia superba* populations of Enderby Land during 1976/77 season. — J. Tokyo Univ. Fish., 68: 25—42.

Klusek Z. and M. Godlewska. 1988. Depth distribution and day-night migrations of krill (BIOMASS III, October—November 1986, January 1987). — Pol. Polar Res., 9: 349—356.

Macaulay M. C., T. S. English and O. A. Mathisen. 1984. Acoustic Characterization of Antarctic Krill (*Euphausia superba*) Swarms from Elephant Island and Bransfield Strait. — J. Crust. Biol., 4 (Spec. No 1): 16—44.

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

Received February 20, 1988
Revised and accepted April 15, 1988

5. Streszczenie

Zarejestrowane akustycznie skupienia kryla zostały podzielone na podstawie ich przekroju poprzecznego na regularne, nieregularne i warstwy. Stwierdzono, że formy regularne występują najczęściej wiosną, w czasie jasnej pory dnia, zaś formy nieregularne najczęściej spotyka się latem w godzinach nocnych. Formy regularne odpowiadają skupieniom poszukującym pożywienia, charakteryzującym się dużym zagęszczeniem osobników i jednorodną strukturą gęstości, podczas gdy formy nieregularne odpowiadają skupieniom odżywiającym się (według klasyfikacji Hamnera, 1984). Średnia gęstość kryla w skupieniu jest najniższa w godzinach nocnych i osiąga maksimum we wczesnych godzinach rannych. Histogramy gęstości w dwugodzinnych przedziałach czasowych wykazują wyraźne różnice dla dnia i nocy, i tylko nieznacznie różnią się dla okresu wiosny i lata antarktycznego.