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All-year populational studies of *Euphausiacea (Crustacea)* in the Admiralty Bay (King George Island, South Shetland Islands Antarctic *)

ABSTRACT: *Euphausia superba* and *E. crystallorophias* were the dominant species in the area studied, *Thysanoessa macrura, E. frigida* and *E. triacantha* were also present. The abundance of krill was changing during the year; minimum occurred between March and August and maxima between December and February and from September till November. Age structure of three most frequently occurring species showed seasonal variations. The periods of development and reproduction were different for *T. macrura, E. erystallorophias* and *E. superba.*

KEY WORDS: Antarctic, krill, *Euphausiacea,* population studies.

1. Introduction

So far the studies on the distribution and changes in the population of krill have been carried out mainly in summer in the open waters of the Antarctic (John 1936, Bargmann 1945, Marr 1962, Baker 1965, Ševtcov and Makarov 1969, Makarov 1972, Dzik and Jażdżewski 1978, Jażdżewski et al. 1978). Since the time when Arctowski Station was set up in the Admiralty Bay continuous biology and populational studies of krill have been carried out there (Jackowska 1980, Kittel 1980a, Rakusa-Suszczewski and Stępnik 1980). The yare of the complex investigations on the functioning of the nearshore Antarctic ecosystem (Rakusa-Suszczewski 1980). This paper gives an analysis of the species composition and population structure of the family *Euphausiacea.* For the first time such observations have been carried out throughout the whole year.

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2. Materials and methods

The winter of 1979 was exceptionally mild and the Admiralty Bay did not freeze. This had enabled krill-sampling during the entire year. Catches were made in the Admiralty Bay and in Ezcurra Inlet in the neighbourhood of Arctowski Station. Description of the region is given by Rakusa-Suszczewski and Stępnik (1980). About 250 trawls were made in the period between 12 December 1978 and 30 November 1979. The works were carried out from a small fishing boat "Dziunia" which dragged a krill net tied to a steal rope. The net 9 meters long was spread over a frame 2 × 1 meters. Mesh size of the front part of the net was 6 mm. The end part of the net was made of a dense fabric (mesh size 60 μ) which prevented krill from too much crushing. The trawing tool was similar to one used earlier by Kittel (1980). The depth of trawls was read from the length of the net-supporting rope and its angle of inclination to the surface. Most catches were made at depths between 100 meters and the surface. The net was hauled behind the boat with the average speed of about 1.5 knots. The average time of hauling was 20 minutes.

Small catches of kril, to about 1 kg, were preserved whole in 4% formaline; samples of 1 kg were taken at random for preservation from larger catches. Subsequently 150 individuals of *Euphausiacea* were taken at random from each sample. The species were identified, and the length was measured with the accuracy to 1 mm between the front edge of the eye and the end of telson. The stages of development were distinguished with divisions into juvenes, immature and mature males, immature and mature females and gravid females (Dzik and Jażdżewski 1978, Kittel and Presler 1980). From some samples all the individuals of species occurring in minority were taken out and identified. The percent contribution of various development stages are shown by adding the results of all the the monthly catches separately for each species. The results for the 2 mm length classes are shown in such a way, that, for instance, class 30 to 32 mm includes individuals 30 and 31 mm in length, class 32 to 34 includes individuals of 32 and 33 mm, and so forth. Altogether 8606 individuals of *Euphausia superba* Dana were analysed; 9797 individuals of *Euphausia crystallorophias* Holt and Tattersall; and 3610 representatioves of *Thysanoessa macrura* G. O. Sars.

The average body length for each species in each sample was measured, and the wet weight corresponding to a given length was found from a regression curve (Sahrhage 1977, Rakusa-Suszczewski and Stępnik 1980). Knowing the weight of every catch, and also the percent contribution of individual species and the average wet weight of the representative of each species, it was possible to estimate the numbers of individuals of *Euphausia superba, E. crystallorophias* and *Thysanoessa macrura* in a given catch. The results for all months were added and the number of individuals of each species was calculated in an average monthly krill-catch.

3. Results

Five species of *Euphausiacea* were found to occur in the Admiralty Bay in the period between 12 December 1978 and 30 November 1979. They were *Euphausia superba, Euphausia crystallorophias, Thysanoessa macrura, Euphausia frigida* Hansen and *Euphausia triacantha* Holt and Tattersall. Usually *E. superba* or *E. crystallorophias* dominated in the particular catches. The quantities of *Crustacea* fished in one catch varied from zero to about 15 kg. The highest amounts were caught between December and February and between September and November (Fig. 1). A sudden decrease in the catches occured in the begining of

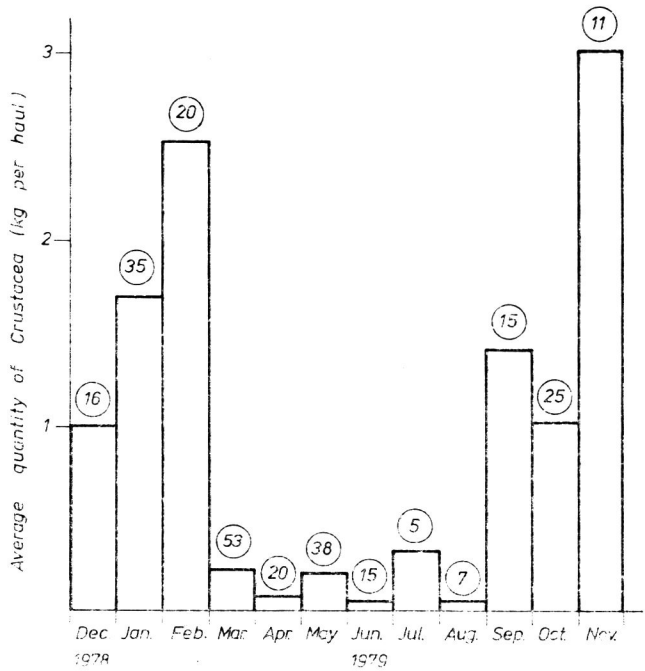

Fig. 1. Annual changes of the wet weight of *Crusstacea* found in the Admiralty Bay. The following numbers of hauls have been made during the consecutive months between December 1978 and November 1979

March; in the period between March and August there were at most a few hundred gramms of *Crustacea* in every sample.

Different species occurred during the year in varied quantitative proportions. In the period from December 1978 till February 1979 a similar numbers of individuals of *E. superba* and *E. crystallorophias* were caught (Fig. 2), however, because of the greater individual weight of *E. superba*, this species dominated in the biomass of *Crustacea*. In March the quantities of *E. superba* found in the catches suddenly dimi-

nished. This prevailed until September, when a new increase in the numbers of *E. superba* was observed. Also the quantities of *E. crystallorophias* decreased about threefold in the March catches. Second decrease occurred in June (Fig. 2). Not a single specimen of *E. crystallorophias* was caugth in November. *Thysanoessa macrura* occurred in the Bay in vaying amounts throughout the year, except in December (Fig. 2).

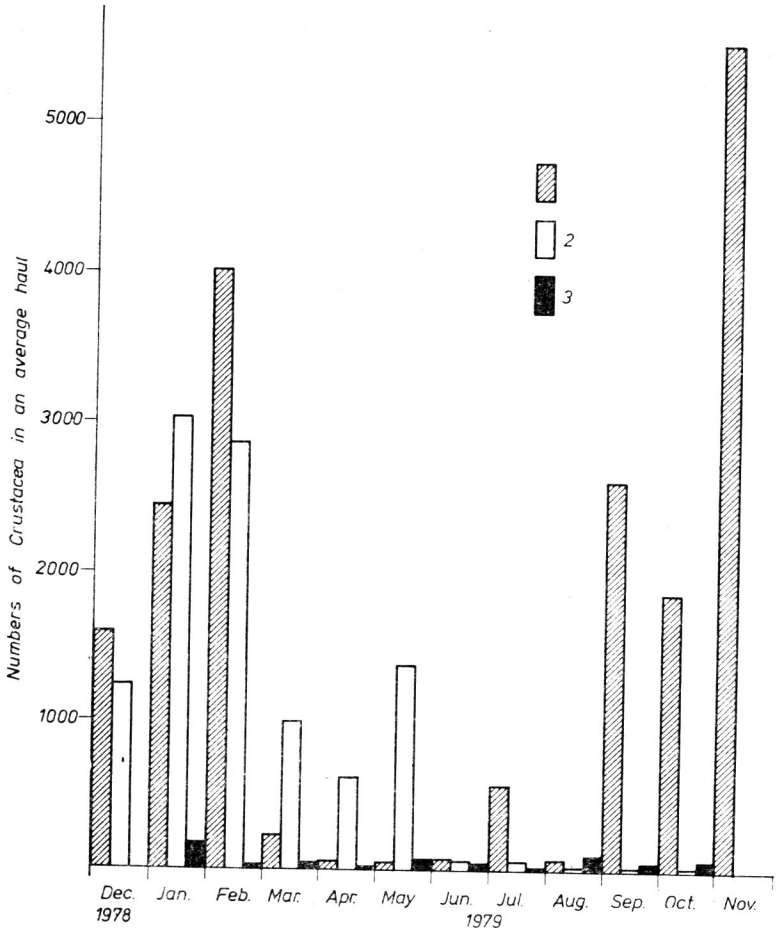

Fig. 2. Annual changes in numbers of the three most frequently occuring species of *Euphausiacea* in the Admiralty Bay
1 — *Euphausia superba*, 2 — *Euphausia crystallorophias*, 3 — *Thysanoessa macrura*

Euphausia frigida was found sporadically in the period between March and July. Altogether only about 160 speciments of this species were found in the catches From March till July only eight specimens of *E. triacantha* were observed.

Euphausia superba

In the period investigated there were substantial differences in the population length distributions. In Austral summer (December-February) two size-classes were noted (Fig. 3). At this time the length of all the specimens had increased, however, smaller individuals and thus younger, grew faster, and so in March, the clear division into two length classes, had disappeared. From March till August the numbers of large individuals decreased and the mean length of the population had shortened (Table I). The populationn length distribution had expanded without a distinct modal value (Fig. 3). From September untill February 1980 the length of *E. superba* individuals had grown again with a clear distinction of the modal value (Fig. 3).

There are several characteristics of the structure of the percent distribution of particular development stages (Fig. 4). Twice in the year there was a greater contribution of juvenile forms. In the period of a diminished juvenes contribution there had increased the participation of immature males and females. Mature males were found during the entire year and their participation was changeable. On the other hand mature females did not occur from July untill September. Gravid females were caught in summer 1979 and 1980 (Fig. 4).

The mean length of individuals in all the stages of development had grown during summer (Table I). A gradual decrease of the mean lengths was noted since April. The minimum mean length of individuals in all the stages was found in August and from this time on, there was an increase of the mean length. In the summer of 1980 the average length of individuals in all the stages of *E. superba* was greater than during the summer of 1979 (Table I).

Euphausia crystallorophias

A very small amount of specimens of this species had been caught in August, September and October; the percent contribution of the various stages and the average lengths are, therefore, not reliable. Not even one specimen was found in the November catches.

The length distribution of *E. crystallorophias* differs substantially from that of *E. superba* (Fig. 5). During the entire year there had occurred only one size group with a distinct modal value. Since December till April there was an apparant increase in length which equalled in these months successively 1.3 mm; 1.2; 0.5; 0.6. During next months the length distributions remained virtually unchanged. Next increase in lengths was noted in the subsequent summer season of 1980 and at that time the length of *E. crystallorophias* was greater than in summer 1979 (Fig. 5).

The characteristic feature of the distribution structure of development stages in the occurrance of juvenes during both summer seasons in the period between December and February (Fig. 6). After a decrease of juvenes numbers in the summer of 1979 an increase of immature stages was noted. A decrease in the contribution of immature forms corresponded with an increase of mature stages. Gravid females were only found in December of 1979 (Fig. 6).

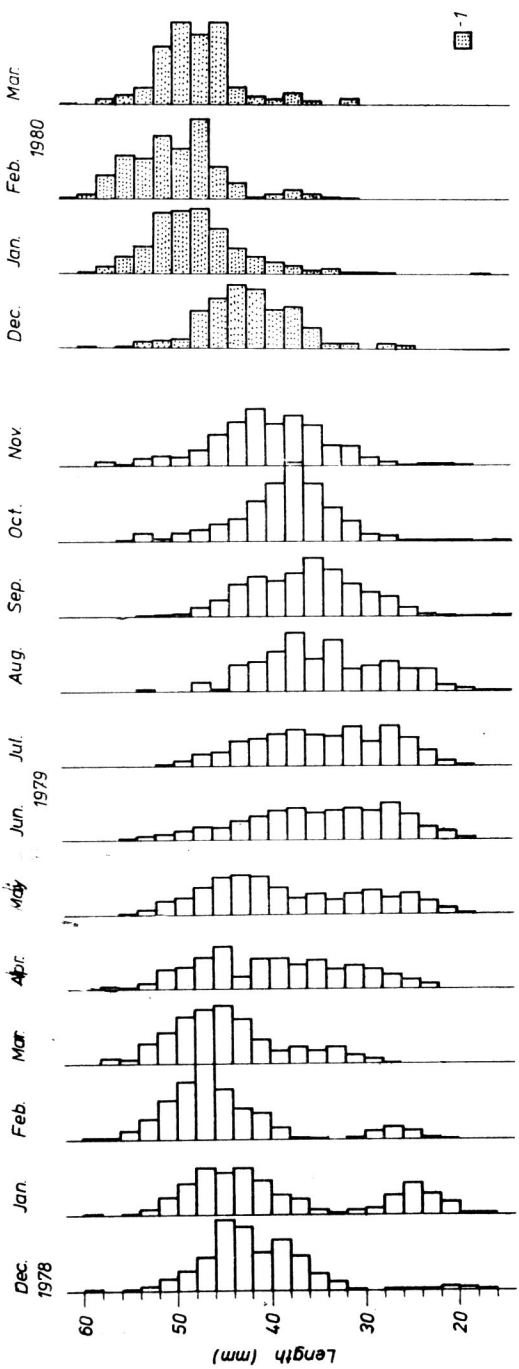

Fig. 3. Annual changes in the population size distribution of *Euphausia superba* in the Admiralty Bay
1 — according to Jackowska 1980.

Table I

Average length ($\bar{x}$) and standard deviation of *Euphausia superba* development stages during consecutive months

Months	Juveniles		Immature males		Mature males		Immature females		Mature females		Females with eggs		Numbers of measured specimens
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	
December 1979	25.0	7.8	43.2	4.0	48.5	2.9	36.4	4.0	40.2	3.3	44.5	3.1	266
January 1979	24.4	4.4	44.3	4.2	48.8	3.7	36.5	6.2	42.1	3.4	46.6	3.3	1056
February	26.0	3.0	46.3	3.9	48.8	3.4	37.0	6.9	44.4	2.7	48.3	3.4	742
March	30.4	3.1	45.7	5.4	50.0	5.2	41.2	5.0	46.8	3.4	49.5	2.1	577
April	27.7	3.9	42.6	6.8	48.3	4.8	37.9	6.3	46.8	2.5	—	—	569
May	25.1	3.2	40.5	6.8	49.8	3.9	39.7	5.5	45.9	4.4	—	—	846
June	25.8	3.1	35.2	5.1	47.1	3.8	37.1	5.2	42**)	—	—	—	416
July	25.1	2.5	33.7	4.5	44.4	3.3	35.7	5.1	—	—	—	—	749
August	24.7	2.6	33.4	4.5	41.9	4.0	35.0	4.7	—	—	—	—	153
September	25.6	2.4	33.4	3.8	43.2	3.8	36.2	5.0	—	—	—	—	1110
October	26.8	4.0	36.1	3.1	44.2	4.6	37.4	4.3	48**)	—	—	—	1352
November	26.8	3.7	37.8	4.0	46.2	5.3	37.4	4.2	46.5	4.1	—	—	770
December*)	31.6	5.5	43.0	3.6	52.0	4.3	38.9	3.9	41.8	3.7	47.9	3.7	549
January 1980*)	34.0	5.2	47.9	4.0	50.4	3.2	43.8	3.5	45.3	3.2	47.6	3.7	1049
February*)	35.8	2.2	51.6	3.6	52.6	3.3	45.5	2.3	47.6	2.9	51.5	3.9	1068
March*)	35.3	2.9	49.1	3.9	49.7	3.2	44.9	1.9	46.9	2.7	—	—	192

*) after Jackowska 1980

**) only one specimen

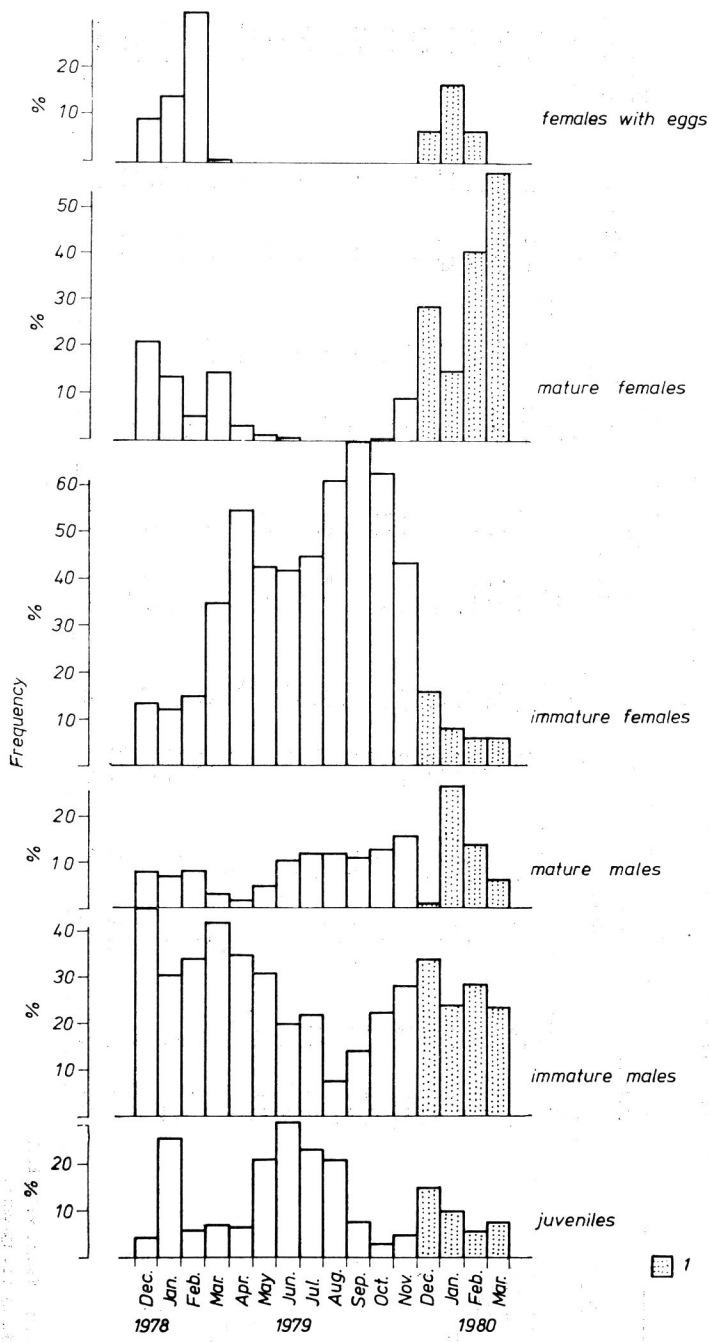

Fig. 4. Annual changes in the percent distribution of *Euphausia superba* development stages in the Admiralty Bay
1 — according to J a c k o w s k a 1980.

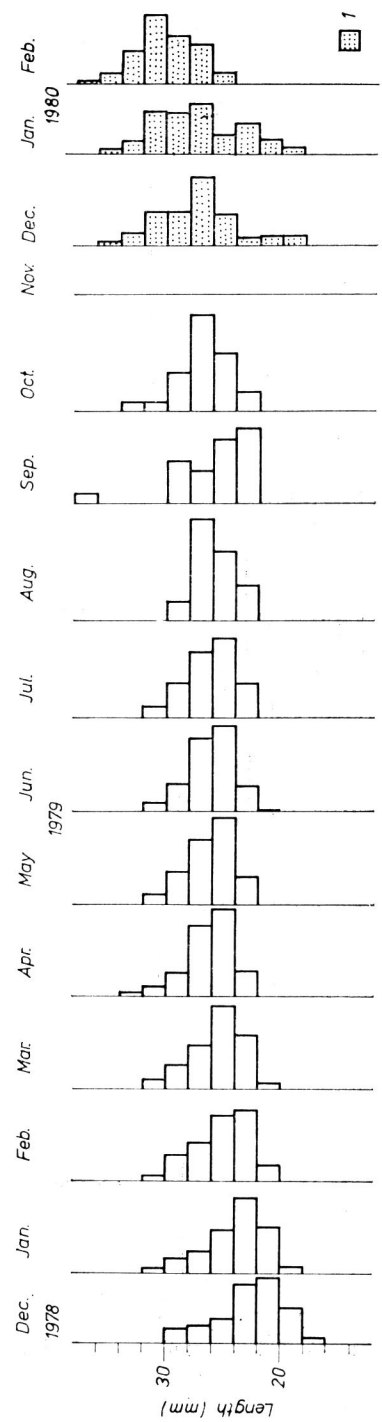

Fig. 5. Annual changes in the population size distribution of *Euphausia crystallorophias* in the Admiralty Bay
1 — according to J a c k o w s k a 1980.

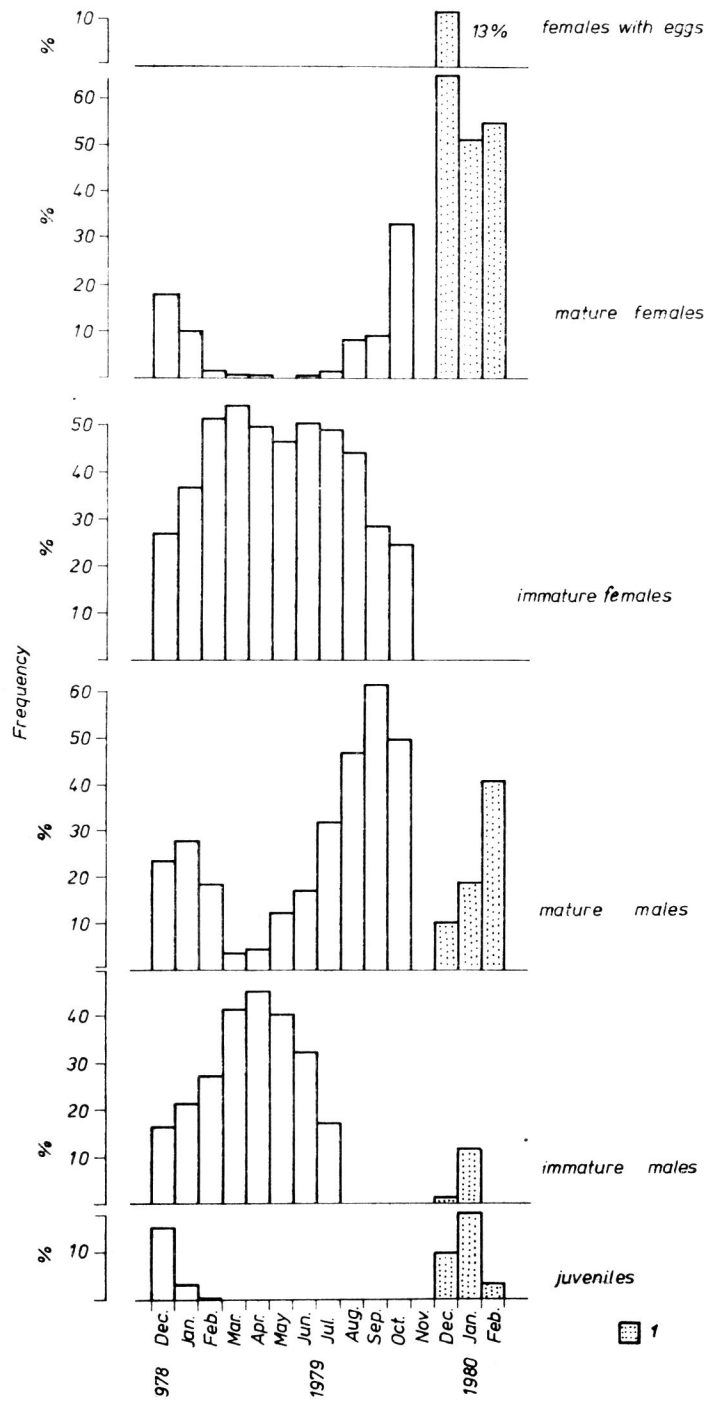

Fig. 6. Annual changes in the percent distribution of *Euphausia crystallorophias* development stages in the Admiralty Bay
1 — according to J a c k o w s k a 1980.

From December till March 1979 there was an increase in the mean length of individuals of all stages of development (Table II). In the next months, the lengths of immature stages did not undergo any substantial change; on the other hand, the length of mature forms had decreased (Table II).

Thysanoessa macrura

This species was not found in December. During the remaining months it was present in much variable quantities. In February, April, July and November the numbers caught were so small, that the results should be treated with much caution.

During the entire year this species formed one size-and-age group. Untill May an apparant increase in length (2.5 mm) was noted (Fig. 7). In the next months the length distribution had changed only slightly.

Juvenile forms of this species were caught most of the time in the year, but their highest percent contribution in the total numbers occurred in January and November (Fig. 8). Immature females dominated during winter. Their contribution decreased since July, and corresponded with an increase of mature females. Gravid females were fished between August and October (Fig. 8).

Compared to the species described earlier, no clear tendencies were noted in the change of the mean length of individuals in various development stages. However, an increase in length within many stages was apparent during the summer. This was followed by a decrease in length in the next months (Table III).

4. Discussion

Earlier investigations carried out in the Admiralty Bay during summer revealed the presence of three species of *Euphausiacea: Euphausia superba, E. crystallorophias* and *Thysanoessa macrura* (Jackowska 1980, Kittel 1980, Rakusa-Suszczewski and Stępnik 1980). The present investigations carried out for the first time during the whole year-round, showed that other species such as *Euphausia frigida* and *Euphausia triacantha* also occur in the bay. Thus, all the species of *Euphausiacea* characteristic for the Antarctic (Zimmer 1914, Tattersall 1924, Ruud 1932, Rustad 1930, 1934, Lomakina 1964, Jażdżewski et. al 1978) occur in Admiralty Bay.

The highest numbers of *Euphausiacea* in the Bay were found during the austral summer and spring. In many summer catches two species, *Euphausia superba* or *E. crystallorophias* were dominant. Presumably they were forming swarms in the bay at that time. *E. superba* formed swarms also in the spring. This species was dominant both in terms of numbers and biomass troughout most of the year.

Table II

Medium length ($\bar{x}$) and standard deviation of *Euphausia crystallorophias* development stages during consecutive months

Months	Juveniles		Immature males		Mature males		Immature females		Mature females		Females with eggs		Number of measured specimens
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	
December 1978	20.1	2.3	19.8	1.3	23.1	2.7	21.8	2.3	25.7	3.0	—	—	371
January 1979	20.8	2.7	21.2	1.6	24.6	2.6	23.2	2.2	27.2	3.1	—	—	1956
February	22.0	1.2	23.8	2.3	25.3	2.6	24.8	2.5	30.0	1.8	—	—	625
March	—	—	24.2	2.1	27.5	2.3	25.7	2.6	33.3	3.0	—	—	1757
April	—	—	25.0	2.0	27.2	2.8	26.4	2.3	25.5	0.7	—	—	942
May	—	—	24.8	1.7	26.8	2.1	26.5	2.4	—	—	—	—	2937
June	—	—	24.6	1.8	26.5	2.0	26.3	2.2	30.5	3.5	—	—	681
July	—	—	23.8	1.3	25.7	2.1	26.7	2.4	28.8	4.3	—	—	413
August	—	—	—	—	24.7	1.7	25.9	1.4	27.3	1.6	—	—	70
September	—	—	—	—	23.9	1.9	28.0	4.5	27.0	2.8	—	—	21
October	—	—	—	—	26.1	1.8	24.8	2.2	27.9	2.9	—	—	24
November	—	—	—	—	—	—	—	—	—	—	—	—	—
December*)	19.8	1.8	20.8	1.3	24.3	2.2	—	—	28.1	2.8	29.9	3.2	402

*) after Jackowska 1980

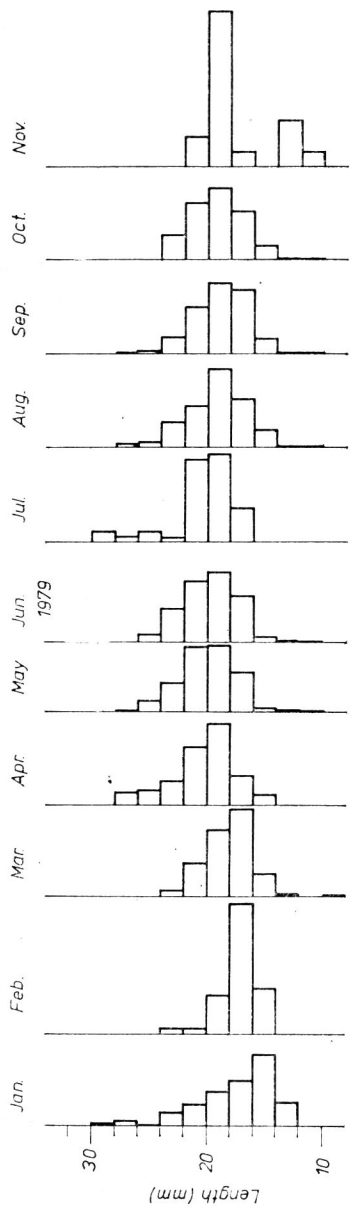

Fig. 7. Annual changes in the population size distribution of *Thysanoessa macrura* in the Admiralty Bay

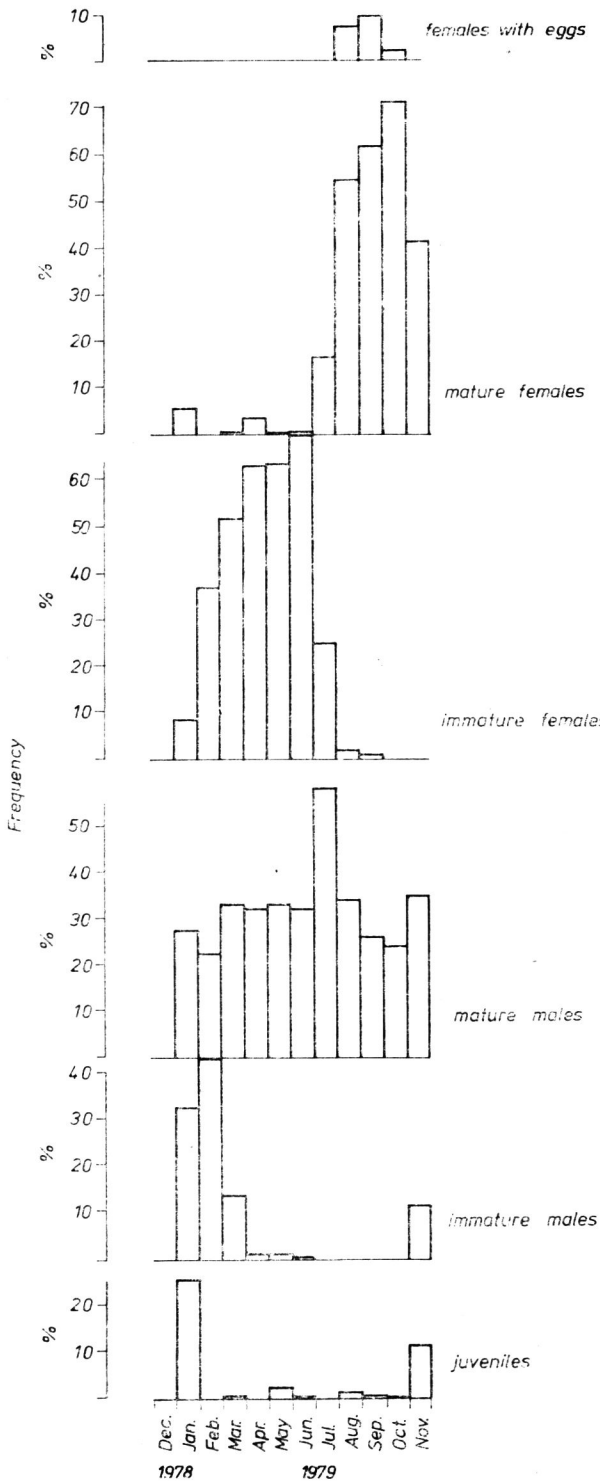

Fig. 8. Annual changes in the percent distribution of *Thysanoessa macrura* development stages in the Admiralty Bay

Tabela III

Medium length ($\bar{x}$) and standard deviation of *Thysanoessa macrura* development stage during consecutive months

Months	Juveniles		Sabadult males		Mature males		Immature females		Mature females		Females with eggs		Numbers of specimens measured
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	
January 1979	15.1	1.7	14.6	1.7	18.9	2.3	20.9	3.0	23.1	2.7	—	—	188
February	—	—	15.9	1.2	17.0	1.1	17.1	1.8	—	—	—	—	40
March	13.7	4.5	16.1	1.6	18.0	1.8	18.0	2.1	26.5	0.7	—	—	400
April	—	—	15*)	—	18.4	1.6	20.4	2.7	24.3	1.5	—	—	92
May	10.6	1.8	13.0	1.6	18.3	1.6	20.3	2.5	27.3	2.1	—	—	1018
June	11.5	0.7	17.0	5.0	18.0	1.6	20.1	2.4	25.0	1.4	—	—	430
July	—	—	—	—	18.8	1.4	19.2	2.3	23.9	3.1	—	—	48
August	12.0	2.7	—	—	17.0	1.9	18.2	2.3	19.9	2.6	20.1	2.3	202
September	10.3	0.5	—	—	16.7	1.7	17.4	3.4	19.3	2.6	19.2	2.1	654
October	10.5	0.7	21*)	—	16.9	1.6	20.7	2.3	19.4	2.1	19.9	1.6	523
November	12.0	1.7	12.5	0.7	17.8	0.4	—	—	19.1	1.4	—	—	17

*) only one specimen

During the observations, characteristic changes were noted in the percent contribution of various development stages in the population of *Euphausi asuperba*. The least contribution of mature males was found in April and from this mounth on their percentage continuously increased. After winter first mature females were obserevd in October and their percentage increased later on. Thus, the maturing of *E. superba* males in the Admiralty Bay had preceded the maturing of females of about six months. In the season investigated there were present gravid females of *E. superba*. They were also caught in the summer of 1978 (Kittel 1980) and 1980 (Jackowska 1980). A large percentage of juvenile forms in the Admiralty Bay during summer had been also noted regularly (Jackowska 1980, Kittel 1980). Year-round studies allowed us for the first time to ascertain the considerable contribution of juvenile forms in the total numbers of *E. superba* during the Antarctic winter. However, these total numbers had much decreased during this period and the increased percentage of juveniles might had resulted from a loss of mature forms. In turn, the mean length of juveniles in winter was the same as in summer, and after the period of a decreased percentage of juveniles at the end of winter, there was a continuous increase of immature males and females. Thus it seems that in the Admiralty Bay, the juvenile forms of *E. superba* appeared twice in the year. The occurance of gravid females during the present and previous seasons was observed only during summer, and so, the development times from eggs to summer juvenile forms and to winter juvenile forms were different.

Characteristic changes have been also observed in the population of *E. crystallorophias*. Since April there was an increase in the percentage of malure males, while an increase in females began in July. Thus, the maturing of males of this species, preceded the maturing of females of about three months. The juvenile forms were found in the summer catches. The percentage of mature males and females increased during winter, however the total numbers of this species decreased. During the next season *E. crystallorophias* was found in much smaller quantities. At this time also gravid females were present (Jackowska 1980). Although, *E. crystallorophias* is a neritic species (Lomakina 1978) it appears that the intensity of its reproduction in the Admiralty Bay in 1979 was not very high and in most part, it had taken place outside the bay.

In the case of *Thysanoessa macrura* population, it is more difficult to ascertain, whether the maturing of males had preceded the maturing of females. During the entire year, the percent contribution of mature males was very large and exhibited only small variations. The percent contribution of the juvenie forms of this species increased twice in the year. Also the changes in the percentage of immature forms indicate that juvenile forms make a large contribution to the population of *Th. macrura* only in the spring or summer.

During the Antarctic winter immature forms of the species investigated were predominant. Only the males of *T. macrura* were mature at this period. Also gravid females of this species were observed earlier compared with other species. *E. crystallorophias* females with eggs occurred three months later after the maximum percent share of gravid females of *Th. macrura* had occurred. In the case of *E. superba*

this maximum was observed one month later after the maximum of *E. crystallorophias*. This shows that the periods of maturing and reproduction for these species differ. Also Makarov (1979) noted that *Th. macrura* produces eggs earlier than *E. superba*.

The highest increase in length of individuals of all the species was observed during the austral summer. At other times the mean length either did not change or had decreased. A decrease of the mean length may result from a greater mortality of larger individuals or from the diminishon of body length of some individuals as was observed in laboratory experimentss (Murano, Segawa and Kato 1979). It seems that both processes may take place in natural conditions. A greater growth increase of krill during the summer had been previously documented by the growth curves of Ruud (1932), Bargmann (1945), Mackintosh (1972).

5. Conclusions

1. All known Antarctic species of *Euphausiacea* that is *Euphausia superba*, *E. crystallorophias*, *E. frigida*, *E. triacantha* and *Thysanoessa macrura* were found to occur in the Admiralty Bay.
2. Highest quantities of *Euphausiacea* in the Admiralty Bay were observed during the austral summer and spring.
3. In terms of biomass *Euphausia superba* was the dominant species during the most part of the year.
4. Males of *Euphausia superba* reached maturity nearly six months earlier than females, while the males of *E. crystallorophias* matured about three months earlier than females.
5. The characteristic feature of the *Euphausia superba* population were two maxima of juvenile forms during the year.
6. The research results indicate that the reproduction of *Euphausia superba*, *E. crystallorophias* and *Thysanoessa macrura* took place in Admiralty Bay. It appears however that in most part, the reproduction of *E. crystallorophias* occurred outside of the bay.
7. The periods of reproduction and life cycles of *Euphausia superba*, *E. crystallorophias* and *Thysanoessa macrura* are different.
8. Highest increases in body length of the investigated *Euphausiacea* were observed during the austral summer.

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6. Summary

Euphausia superba, *E. crystallorophias*, *E. frigida*, *E. triacantha* and *Thysanoessa macrura* were found to occur in the Admiralty Bay in the period between December 1978 and November 1979. Highest numbers of *Crustacea* with *E. superba* as a dominant species were observed during the austral summer and spring (Fig. 1

and 2). Seasonal changes were found in the age structure of the species investigated. Immature forms were dominant in winter (Figs. 4, 6 and 8). Highest quantities of juvenile forms were present during summer. An increased participation of *E. superba* juvenes was observed twice during the year. Gravid females of *E. superba* occurred in December untill February (Fig. 4); of *T. macrura* between August and October (Fig. 8); and of *E. crystallorophias* in December of 1979 (Fig. 6). The development cycles of the species differ on from another. Largest increases in body length of the species investigated were noted during the austral summer (Figs. 3, 5 and 7).

7. Резюме

В период с декабря 1978 до ноября 1979 г. в Заливе Адмиралты отлавливались *Euphausia superba E. crystallorophias E. frigida E. triacantha Thysanoessa macrura*. В период антарктического лета и весны наблюдалось самое высокое количество ракообразных, среди которых преобладал вид *E. superba* (рис. 1 и 2). Возрастная структура исследуемых видов подлежала сезонным изменениям. Зимой преобладали не зрелые формы (рис. 4, 6 и 8). Самое большое количество молодых особей встречалось летом; у *E. superba* — два раза в год. Самки с икрой наблюдались у *E. superba* с декабря по февраль (рис. 4), у *Thysanossa macrura* — с августа по октябрь (рис. 8) а у *E. crystallorophias* — в декабре 1979 г. (рис. 6). Циклы развития исследуемых видов отличались друг от друга. Самые большие приросты длины тела у этих видов были установлены в период антарктического лета (рис. 3, 5 и 7).

8. Streszczenie

W okresie od grudnia 1978 do listopada 1979 w Zatoce Admiralicji łowiono *Euphausia superba, E. crystallorophias, E. frigida, E. triacantha* i *Thysanoessa macrura*. W okresie antarktycznego lata i wiosny łowiono największe ilości skorupiaków wśród których dominowała *E. superba* (rys. 1 i 2). Struktura wiekowa badanych gatunków podlegała sezonowym zmianom. Zimą dominowały formy niedojrzałe (rys. 4, 6 i 8). Największe ilości form juwenilnych łowiono latem. U *E. superba* dwukrotnie w ciągu roku stwierdzono zwiększony udział tych form. U *E. superba* samice z jajami występowały od grudnia do lutego (rys. 4), u *Thysanoessa macrura* od sierpnia do października (rys. 8), a u *E. crystallorophias* złowono je w grudniu 1979 roku (rys. 6). Cykle rozwojowe badanych gatunków różnią się. Największe przyrosty długości u tych gatunków stwierdzono w okresie lata antarktycznego (rys. 3, 5 i 7).

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