# Some Observations on the Feeding Activity of Antarctic Krill in the Indian Sector of the Antarctic Ocean

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南極海インド洋区におけるナンキョクオキアミの摂餌

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**要旨:** BIOMASS 研究 FIBEX 航海が1980/1981に水産庁開洋丸によりインド洋海区において実施された．この機会を利用して ナンキョクオキアミ(*Euphausia superba*) の摂餌行動の観察を行った．

調査は，1980年12月中・下旬の第1期，1981年1月中・下旬の第2期，2月上旬の第3期にわたって実施された．材料は，表面びき ORI ネットと魚群探知機とネットレコーダーを利用した KOC-A 中層びきネットによって採集したナンキョクオキアミを用いた．胃および体節により区分した消化管に内容物のある個体の出現状況を成熟個体の雌雄，未成熟個体，幼令個体ごとに経時的に追跡した．また，同一の群れを経時的に追跡採集を行い，垂直移動にともなう摂餌行動の変化をおった．

以上の調査の結果，第1期，第2期ともに，摂餌は1日2回，正午過ぎ (12時～15時) と早朝早く (0時～03時) にピークが見られた．雄，雌について特に明瞭な差はみられないが，幼令個体では摂餌が不活発で，摂餌時間帯も不明瞭であった．第3期は，どのグループも明瞭な摂餌時間帯がなく，また摂餌も不活発であった．同一群からの繰り返し採集調査では，明瞭な結果は得られなかったが，幼令個体の摂餌はやはり不活発であった．

***Abstract:*** The BIOMASS FIBEX Cruise of R/V KAIYO MARU in the Indian Sector of the Antarctic Ocean was conducted from 11 November, 1980 to 18 March, 1981. The investigation could be subdivided into three stages on the basis of the area and the duration: Investigation I (11–26 December, 1980; Long. 60–85°E), Investigation II (16–30 January, 1981; Long. 30–55°E) and Investigation III (31 January–6 February, 1981; Long. 60–70°E).

Feeding activity of the Antarctic krill, *Euphausia superba* DANA, was studied regarding the sexual maturation by examining the digestive tract contents. It seemed that feeding of the krill was active two times a day. In Investigation I the active period of feeding was between 00 and 03 h and 12 and 15 h or between 12 and 18 h in both sexes. With the advance of time (Investigation III) the active period of feeding was different between sexes, and the feeding

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activity varied little in mature female.

From the present examination it was difficult to confirm the relation between the population density causing vertical migration and the feeding activity.

## 1. Introduction

The diel feeding activity of euphausiids has been reported for the Antarctic krill (PAVLOV, 1969, 1974) as well as for the subarctic (PONOMAREVA, 1963) and tropical species (PONOMAREVA, 1971; ROGER, 1973, 1975). PAVLOV (1969) reported that the Antarctic krill moves to a shallow layer (shallower than 15–25 m depth) twice a day, around noon and midnight. He examined the contents in the stomachs and digestive tracts, and concluded that these upwards movements of the Antarctic krill are closely related to the feeding activities that occur twice a day in the surface water. However, as far as the diurnal-nocturnal movements of the Antarctic krill are concerned, not only general information but also the information related to their feeding activities is still uncertain and scarce. The present study had an aim to gather more information on these problems, especially on the time of feeding. Furthermore, from the viewpoint of feeding patterns by age and sex groups, analysis was attempted.

The BIOMASS Cruise of R/V KAIYO MARU, Japan Fisheries Agency, to the Indian Sector of the Antarctic Ocean was conducted from 11 November, 1980 to 18 March, 1981. We participated in the cruise, and made studies on the problems mentioned above.

## 2. Materials and Methods

The investigation of the R/V KAIYO MARU Cruise was divided into three stages on the basis of the duration and the area; Investigation I (11–26 December, 1980) covering the area of Lat. 61°S down to the pack ice edge between Long. 60 and 85°E, Investigation II (16–30 January, 1981) covering the area of Lat. 63°S down to the pack ice edge between Long. 30 and 55°E, and Investigation III (31 January–6 February, 1981) covering the area of Lat. 62°S down to the pack ice edge between Long. 60 and 70°E.

Krill samples for the examination were collected by ORI-300 net of 160 cm in diameter, 3 mm in mesh size and 7.5 m in side length, or by KOC-A net of $3 \times 3$ m in mouth frame, 5.6 mm in mesh size and 16 m in side length. Both nets were selectively used, such as ORI-300 for surface towing and KOC-A for subsurface. KOC-A net with an acoustically opening-closing device was operated by monitoring the krill patch with a scientific echo sounder (Furuno FQ-30: 200 kHz) and the net recorder.

Net towing was conducted randomly at different times in each investigation period. Although sampling was not always made, fifty specimens for the study were picked up at random when the catch per townet exceeded *ca.* 2 kg. The position of contents in the digestive tracts of all 50 specimens in relation to the abdominal segmentation was examined soon after catch. The catches of 2 kg per net were 5 of 17 ORI-300 net trials and 26 of 35 KOC-A trials. Another series of sampling was

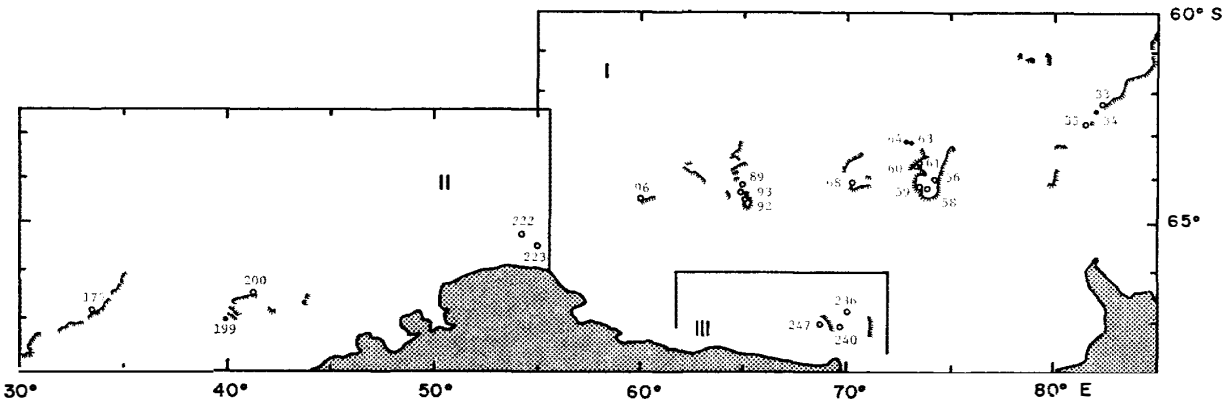


*Fig. 1. Sampling stations in the sea area close to pack ice edge. ●: ORI-300 net sampling stations, ○: KOC-A sampling stations, ////: pack ice.*

*Table 1. List of samples.*

| Investigation period | Area (Lat. S / Long. E) | Number of samples: Net used ORI-300 | KOC-A | Sampling time (local) 00–03 | 03–06 | 06–09 | 09–12 | 12–15 | 15–18 | 18–21 | 21–24 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I. 11–26 December, 1980 | 59°–65° 60°–85° | 4 | 16 | 2–1 | 2–2 | 0–0 | 0–0 | 0–4 | 0–6 | 0–1 | 0–2 |
| II. 16–30 January, 1981 | 63°–67° 30°–55° | 1 | 4 | 0–0 | 0–0 | 1–0 | 0–2 | 0–1 | 0–1 | 0–0 | 0–0 |
| III. 31 January –6 February, 1981 | 66°–68° 60°–70° | 0 | 6 | 0–0 | 0–0 | 0–0 | 0–2 | 0–1 | 0–2 | 0–1 | 0–0 |
| Total | | 5 | 26 | 2–1 | 2–2 | 1–0 | 0–4 | 0–6 | 0–9 | 0–2 | 0–2 |

In the column of the sampling time, the numbers on the left show ORI-300 net samples and those on the right are KOC-A samples.

repeatedly performed from the same patch at intervals of one hour to examine the time-feeding relation of the krill, and the same observation on digestive tracts was made.

Sex and developmental phase identification was made on all specimens. Concerning the classification of the developmental phases of females, the practical method employed was as follows: Equivalent phase numbers in MAKAROV and DENYS (1981) classification system are shown in parentheses. A "mature" female has a swollen body (III D). A "spent" female has also a swollen body but the eggs had been laid, so that the empty part of ovary can be seen (III E). An "immature" female which has not a swollen body yet includes specimens both with (III B) and without (II B and III A) spermatophore. No classification of developmental phases in the "male" was made because of technical difficulties on board. A "juvenile" was easily classified by examining the external sexual characteristics (I).

Sampling stations are shown in Fig. 1, and sampling time was grouped in 8 periods at three hour intervals as shown in Table 1. Time was all expressed in local time.

In this paper conception of the word "patch" does not necessarily agree with that of MAUCHLINE (1980a, Table 1), but means a dense aggregation of the krill recognizable by visual observations and by the records of echo sounder.

## 3. Results

### 3.1. Investigation I (11–26 December, 1980; Long. 60–85°E)

In Investigation I, 4 and 16 samplings were performed by ORI-300 net and KOC-A net, respectively. Concerning the sampling time, as shown in Table 1, samples of ORI-300 (surface tow) were obtained only in the periods of 00 h–03 h and 03 h–06 h. Samples of KOC-A (subsurface tow, 13–65 m depth) were obtained in each period except 06 h–09 h and 09 h–12 h. Although sampling was still inadequate to discuss

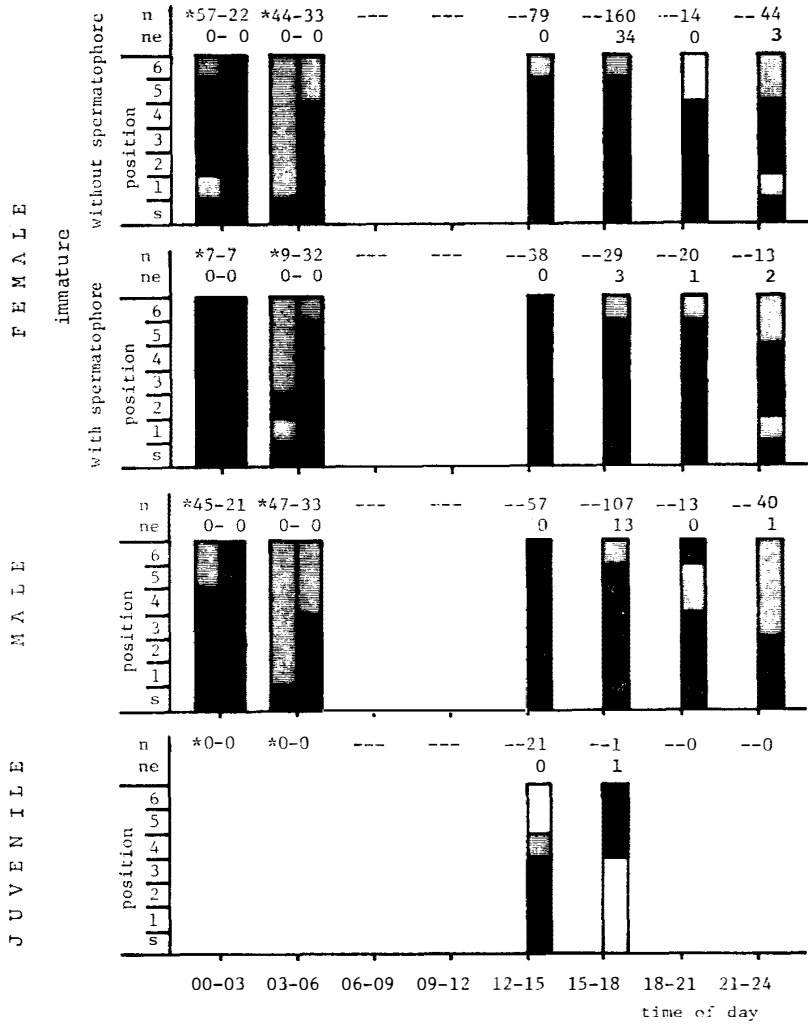


*Fig. 2. Result of Investigation I. Ingested diet passed through stomach (s) to intestine in relation to the position of abdominal segments (1–6). n: total number of specimens examined, ne: number of specimens of which stomach is empty, n with *: samples taken by ORI-300 net, n without *: samples taken by KOC-A, presence of ingested diet in ▭ 0%, ▤ 1–49%, and ■ ≧50% of specimens examined.*

the diel movement in relation to the feeding activity, some diel feeding rhythm was observed. As shown in Fig. 2, the feeding activity was represented by the degrees of appearance frequency of the specimen of which stomach and digestive tract of each abdominal segment contains some amount of contents, such as 0%, 1–49% and more than 50%. Figure 2 indicates that male and female both with and without spermatophore showed the same tendency of diel feeding activity. Feeding activity

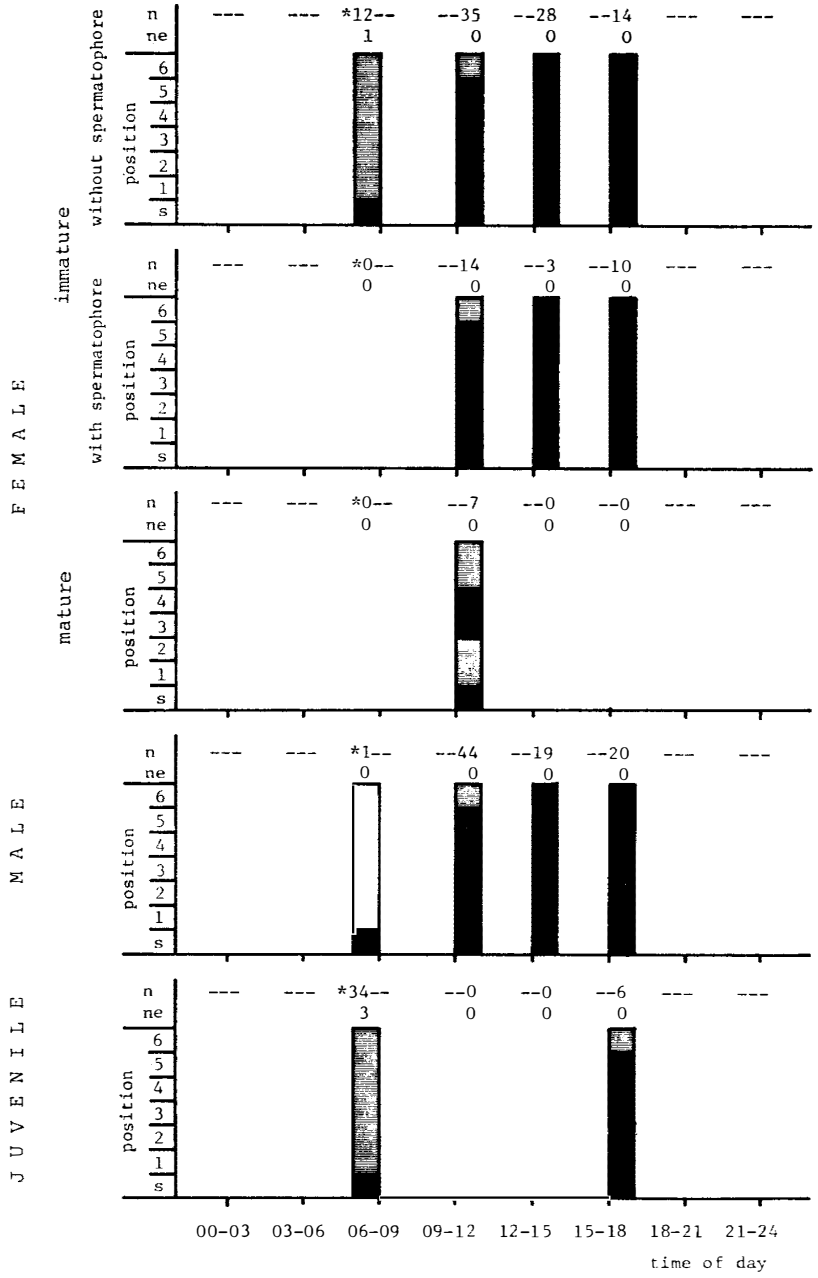


*Fig. 3. Result of Investigation II. Ingested diet passed through stomach (s) to intestine in relation to the position of abdominal segments (1–6). n: total number of specimens examined, ne: number of specimens of which stomach is empty, n with *: samples taken by ORI-300 net, n without *: samples taken by KOC-A, presence of ingested diet in □ 0%, ▤ 1–49%, and ■ ≧50% of specimens examined.*

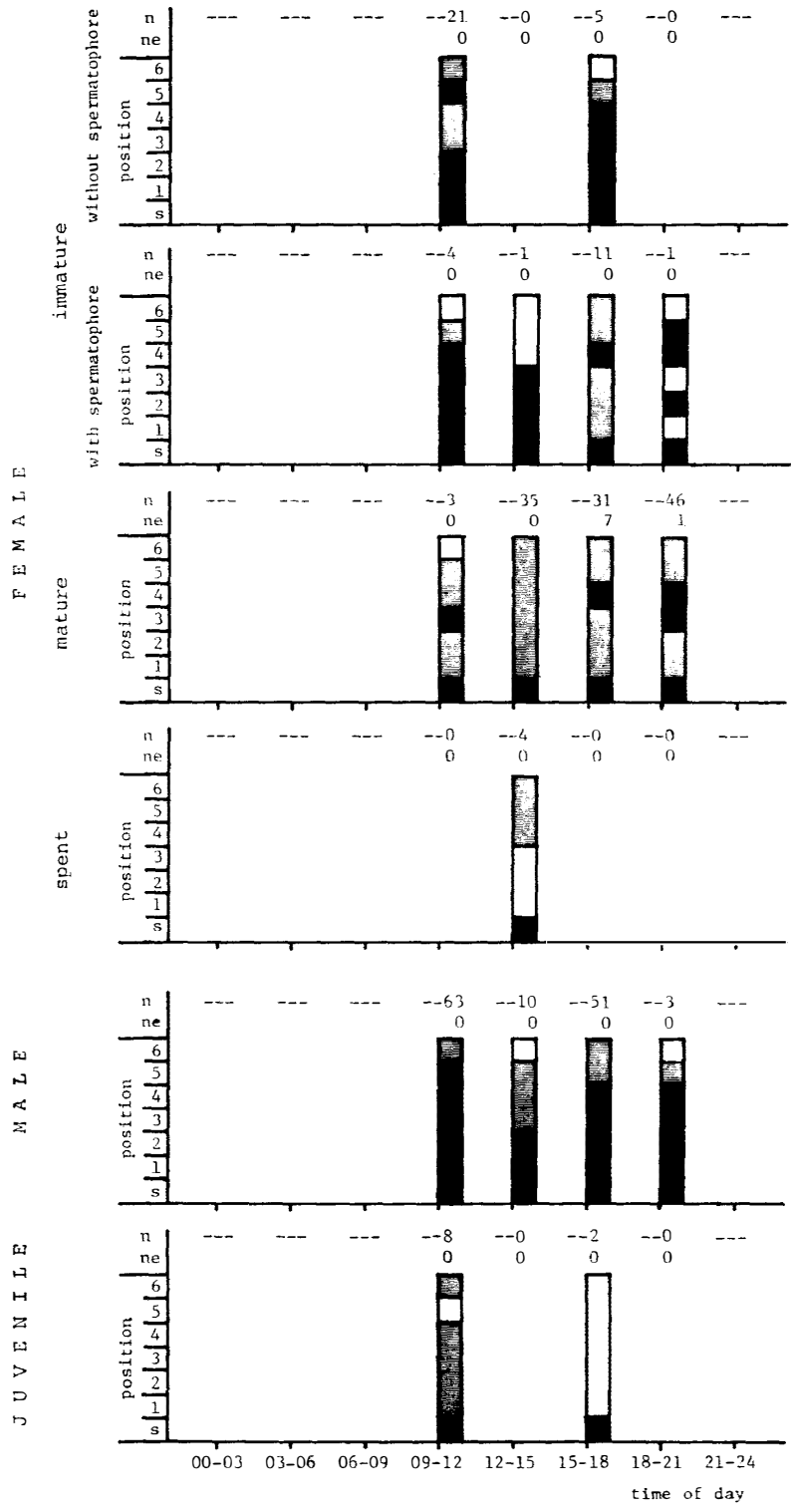


*Fig. 4. Result of Investigation III. Ingested diet passed through stomach (s) to intestine in relation to the position of abdominal segments (1–6). n: total number of specimens examined, ne: number of specimens of which stomach is empty, n with *: samples taken by ORI-300 net, n without *: samples taken by KOC-A, presence of ingested diet in* ▭ *0%,* ▤ *1–49%, and* ■ *≧50% of specimens examined.*

level of the above three groups was generally high in the periods of 00 h–03 h and 12 h–15 h with contents in all or most parts of digestive tracts and was relatively low

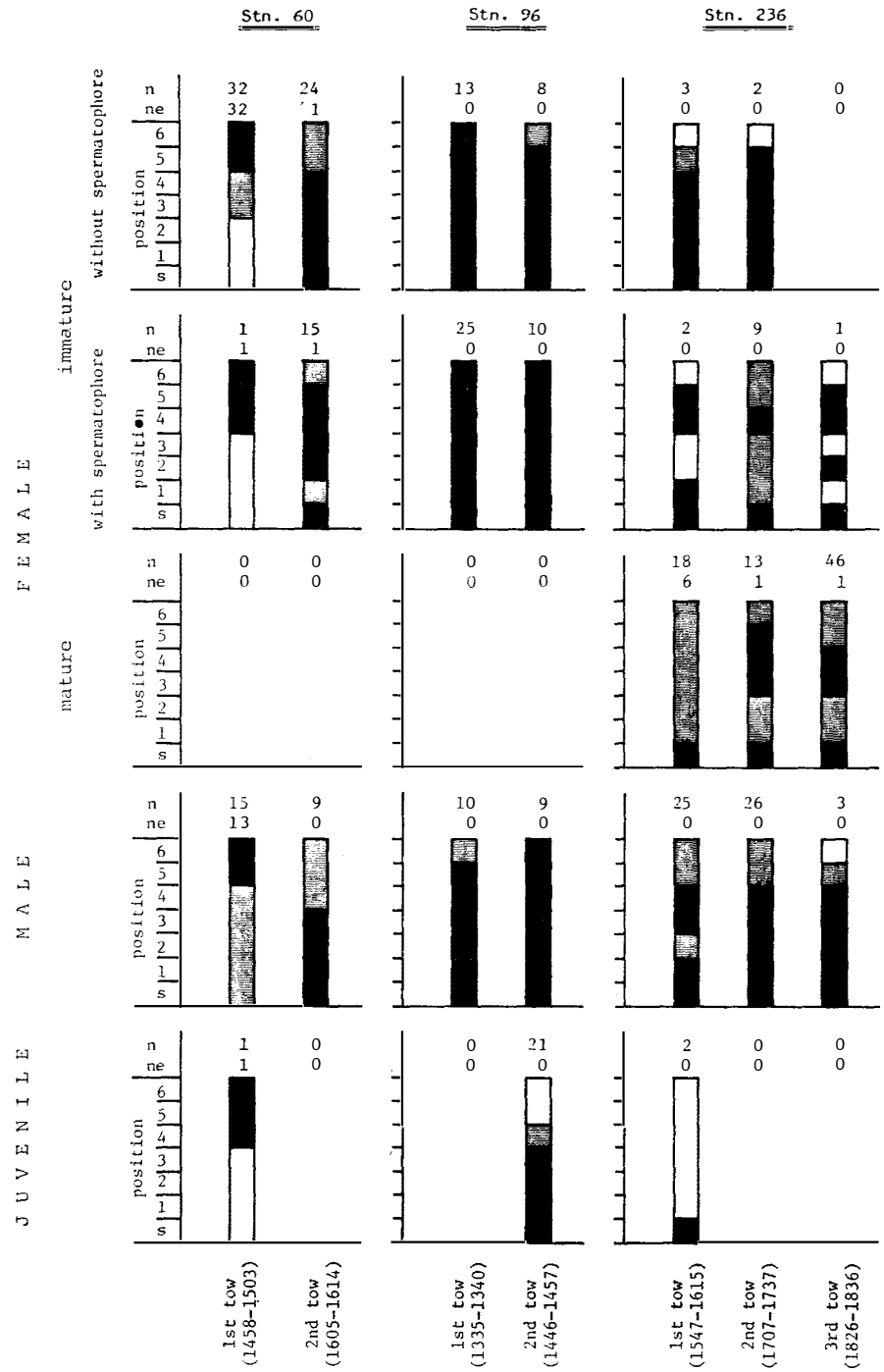


*Fig. 5. Repeated samplings at three stations. Ingested diet passed through stomach (s) to intestine in relation to the position of abdominal segments (1–6). n: total number of specimens examined, ne: number of speciments of which stomach is empty, n with *: samples taken by ORI-300 net, n without *: samples taken by KOC-A, presence of ingested diet in ▭ 0%, ▤ 1–49%, and ■ ≧50% of specimens examined.*

in the periods of 03 h–06 h and 18 h–21 h. It was very low in the period of 21 h–24 h with less appearance frequency of contents in posterior parts of digestive tracts. Samplings in the periods of 06 h–09 h and 09 h–12 h are lacking, but the above result may suggest that feeding of the Antarctic krill occurs after midnight and noon and may support the result obtained by PAVLOV (1969). Concerning the difference between surface samples of ORI-300 and subsurface samples of KOC-A, it seemed that feeding was less active in the subsurface samples. The data we obtained on juvenile feeding are scarce, but it is clear that the juveniles feed less actively in the periods of 12 h–15 h and 15 h–18 h when males and females with spermatophore and without spermatophore feed actively. It is uncertain whether this phenomenon is due to the different feeding time of juveniles and other age groups or due to some other reasons.

### 3.2. Investigation II (16–30 January, 1981; Long. 30–55°E)

In Investigation II, 1 and 4 samplings were performed by ORI-300 (surface tow) and KOC-A (subsurface tow; 13–90 m depth), respectively. Samplings were performed in the daytime at 06 h–09 h, 09 h–12 h, 12 h–15 h and 15 h–18 h. Diel feeding activity of immature females with spermatophore and without spermatophore and males showed the same tendency. It was high between 12 h–18 h and quite low in the period of 06 h–09 h (Fig. 3). This result suggests that the Antarctic krill feeds actively after noontime. The season of Investigation II was about 1 month later than Investigation I, but diel feeding activities in I and II seemed alike. Therefore, as a whole the feeding activity is very high around midnight and is reduced between early morning and noon. It increases around noon and begins to decrease in the afternoon.

### 3.3. Investigation III (31 January–6 February, 1981; Long. 60–70°E)

In Investigation III, 6 KOC-A subsurface samplings (20–83 m depth) were performed in the daytime and in the evening. As shown in Fig. 4, different from Investigations I and II, no feeding peak around noontime was observed in sex and age groups of the krill. It seemed that the feeding activity was rather low compared with other investigations, and its peak seemed to be obscure. Concerning the difference of diel feeding activity between the respective groups, it is also difficult to obtain some results owing to the scarcity of data. However, as seen in the juveniles of Investigation I, juveniles also showed lower feeding activity than other groups, though we have no explanation for this phenomenon.

### 3.4. Repeated samplings from the same krill patch

Sampling was carried out at three different stations, such as Stn. 60 (18 December, 1980), Stn. 96 (24 December, 1980) and Stn. 236 (3 February, 1981). At each station two or three samplings were carried out at intervals of about one hour by KOC-A net. As shown in Fig. 5, the feeding activity is relatively low except males and females at Stn. 96. It is also clear that the feeding activity of juvenile krill is quite low at all stations. As suggested in the preceding section, the sampling time at Stn. 96 (1335–1340, 1446–1457) belongs to the active feeding period of 12 h–15 h. The

feeding activity of juveniles was generally low in the former investigation. Therefore, in this study the same results were obtained as in the former investigation. It is also supported that the feeding condition of the same patch samples much varied with the sampling time except male and female samples of Stn. 96. It is uncertain whether these samples represent the feeding conditions of the whole patch, because sampling was performed at different depths. However, it is possible that the feeding condition of the patch as a whole changes in a short period.

## 4. Discussion

MAUCHLINE (1980b) reviewed and reported that the most active period of feeding of euphausiids was generally at night between 20 h and 06 h but another active period was between 14 h and 20 h. The present examination agrees with his report in the case of immature females and males collected in December and January; the active period of feeding was between 00 h and 03 h, and between 12 h and 15 h in December (Fig. 2), and between 12 h and 18 h in January (Fig. 3). In February, the feeding

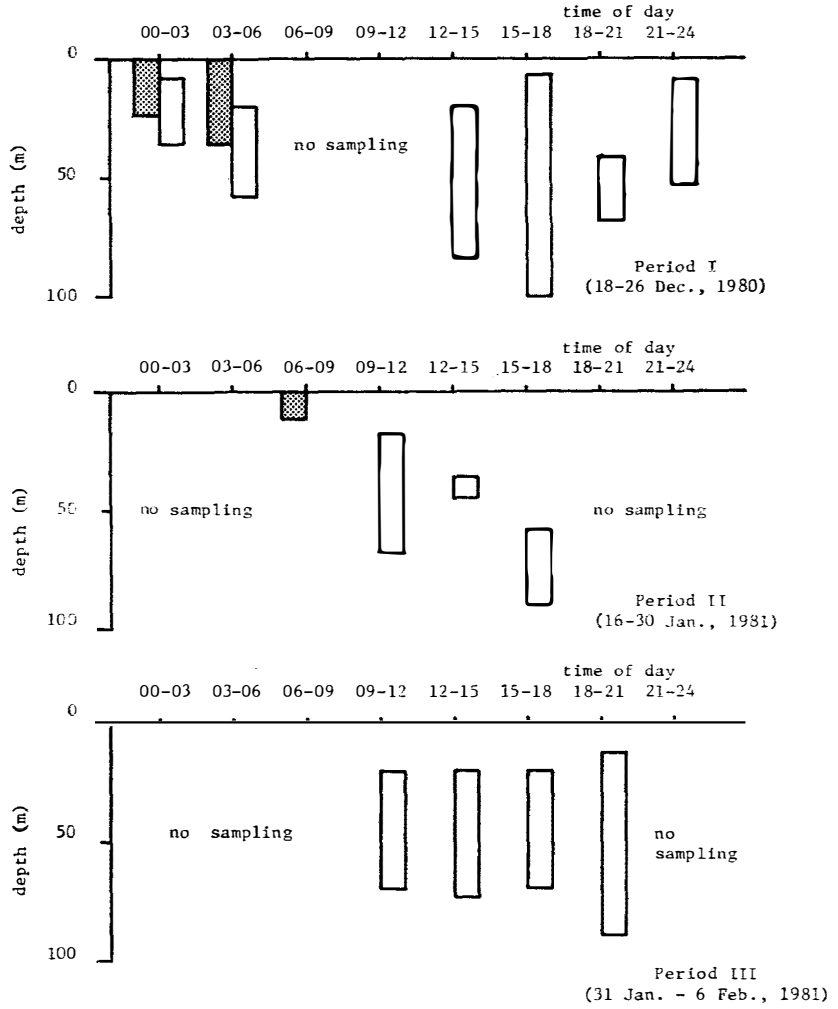


*Fig. 6. Vertical distribution of krill patch collected by ORI-300 net (▨) and KOC-A (□) recorded by scientific echo sounder.*

activity of all age and sex groups seemed to decrease and its peaks also became obscure. At present, we have no clear explanation why the feeding activity changed in late summer. Possibility of seasonal changes may be indicated. However, in the investigation of repeated samplings from the same krill patch, no clear seasonal changes of feeding activity were found. Actually feeding activity in the investigation of repeated samplings in February (Stn. 236) seemed to be low (Fig. 5), yet it is still not clear if seasonal changes really occur. Therefore, at the present stage of the study, it is difficult to conclude that the feeding activity of the krill decreases in late summer and seasonal chages occur.

Concerning the difference in the feeding activity between age and sex groups, it is clear that juveniles show different feeding activity. In all investigations, the feeding activity of juveniles was generally low. We could not observe any diurnal changes in the feeding activity of the juveniles. However, some diurnal variation would be found when much more frequent samplings were performed. It remains unexplained why the feeding activity of juveniles is low compared with other groups.

There are several discussions on the relation between vertical migration and feeding activity; some migrant species feed in the deeper water during the day, and stay in the surface water at night. *Thysanopoda tricuspidata* (ROGER, 1973) and *Meganyctiphanes norvegica* (SAMEOTO, 1980) are examples of those euphausiids. Even in no-migrant species such as *Nematobrachion sexspinosus* (HU, 1978), the diel feeding activity pattern was reported. The Antarctic krill (*Euphausia superba*), migrant species, is reported to feed in the shallow water around noon and midnight (PAVLOV, 1969, 1974). In the present study, these problems were not always dealt with, due to the sampling difficulties. However, some seasonal relation between the feeding activity and the migration depth was supported. As shown in Fig. 6, in early and mid summer (Investigations I and II) when the krill feeds actively and the time of feeding peak is much clear, the migration depth varied, and in late summer when feeding activity seems to decrease, the migration depth is much less varied. It is quite difficult to infer the feeding depth from our data, but some relations exist between the feeding activity and the vertical migration.

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